This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

A 754,446 DUPL

Engin.
TL
701
.K24
1918

M

AERONAUTICAL ENGINES

A critical survey of current practice with special reference to the balancing of inertia forces

By

FRANCIS JOHN KEAN, B.Sc. (Lond.)

First Class Honourman in Engineering; Temporary Lieutenant in
the Army Service Corps; formerly Head of the Motor Car
Engineering Department of the Polytechnic School
of Engineering, Regent Street, London, W.;
one time Lecturer on Experimental
Engineering at McGill University,
Montreal, Canada

29 PLATES INCLUDING 82 ILLUSTRATIONS

SECOND EDITION,
REVISED AND ENLARGED

New York
SPON & CHAMBERLAIN, 120 LIBERTY STREET
London
E. & F. N. SPON, Limited, 57 HAYMARKET, S.W.1
1918

IN. LIBRARY

TL
701
.K24
1918

Copyright, 1918,
By SPON & CHAMBERLAIN

VAIL-BALLOU COMPANY
BINGHAMTON AND NEW YORK

Transferred to
Engineering Lib.
7-20-44

PREFACE TO SECOND EDITION

THE contents of this book formed the subject matter of a special course of ten lectures given by the Author at the Regent Street Polytechnic, London, W., during the autumn of 1915 to men of the Royal Naval Air Service, Royal Flying Corps, Designers, and Engineering Students.

My thanks are due to Mr. Robert Mitchell (Director of Education) and Professor Henry J. Spooner (Head of the Engineering School), for the kindly interest they took in my work; also to Mr. Charles Spon for his kind assistance with the book.

A description of the Curtiss and Mercédès aeroplane engines, although included in the Lecture Course, was omitted from the first edition of this book. The present opportunity is taken to insert a brief account of both engines.

FRANCIS JOHN KEAN.

July, 1918.

337211

DEDICATION

THIS BOOK IS DEDICATED TO MY DEAR WIFE
WHOSE CONSTANT SYMPATHY WITH ALL
MY UNDERTAKINGS HAS EVER
ENCOURAGED ME TO
FURTHER EFFORT

CONTENTS

PAGE

PREFACE 3

DEDICATION 4

LIST OF ILLUSTRATIONS 7

CHAP.

I THE NATURE OF THE PROBLEMS 9

II CLASSIFICATION OF AEROPLANE ENGINES . . 14

III RELATIVE ADVANTAGES OF DIFFERENT TYPES OF AEROPLANE ENGINES 21

IV CHOOSING THE NUMBER OF CYLINDERS . . 29

V BALANCING THE SLIDING PARTS OF THE ENGINE 44

VI CARBURATION 55

VII IGNITION 62

VIII TYPICAL AEROPLANE ENGINES 70

APPENDIX 95

INDEX 97

LIST OF ILLUSTRATIONS

FIG. PAGE
1. Diagram to illustrate Horizontal Motion through the Air 9
2. Diagram of Wind Velocities 10
3. Diagram to illustrate Effect of Wind Pressure 11
4. Diagram of Forces, resulting from Wind Pressure 11
5. Rotary Engine 15
6. Air-cooled Vee Engine 16
7. Semi-air-cooled Vee Engine 16
8. Radial Engine, Air-cooled 17
9. Vertical Engine (Overhead Camshaft) 18
10. Vertical Engine (Long Tappet Rods) 18
11. Radial Engine (Water-cooled) 18
12. Water-cooled Vee Engine 19
13. Water-cooled Vee Engine (L-headed Cylinders) 19
14. Water-cooled Vee Engine 20
15. Suction Stroke 30
16. Compression Stroke 30
17. Explosion Stroke 31
18. Exhaust Stroke 31
19. Diagram of Valve Setting and Ignition Timing 33
20. Diagrammatic Sketch showing Arrangement of Pistons and Cranks in a Four-cylinder-in-line Engine 34
21. Diagram of Crankshaft of Six-cylinder Engine 36
22. Arrangement of Six Cylinders about a Fixed Crankshaft 38
23. Arrangement of Seven Cylinders about a Fixed Crankshaft 39
24. Arrangement of Six Cylinders in Two Groups of Three Cranks at 180° 41
25. Diagram to illustrate Simple Harmonic Motion 45
26. Diagram of Inertia Forces acting on the Piston of Air Engine . . 46
27. Arrangement of Piston and Rod to give Simple Harmonic Motion . . 47
28. Arrangement of Six-crank Engine 48
29. Diagram of Inertia Forces of Six-cylinder Vertical Engine with Cranks at 120° (Plate 27) . . . . *at end of book*
30. Arrangement of Eight-cylinder Vee Engine 50
31. Diagram of Inertia Forces of Eight-cylinder Vee Engine, with Cranks at 180° (Plate 28) . . . . *at end of book*
32. Diagram of Primary Inertia Forces of Seven-cylinder Salmson Engine (Plate 29) . . . . *at end of book*
33. Diagram of Primary and Secondary Inertia Forces of Seven-cylinder Salmson Engine (Plate 30) . . . . *at end of book*
34. Diagram of Inertia Forces of Ten-cylinder Anzani Engine (Plate 31) *at end of book*
35. Outline of Mechanism of Nine-cylinder Gnome Engine 53
36. Sectional Drawing of Carburettor of the Jet Type 56
37. Claudel-Hobson Carburettor as arranged for Aviation Work (Plate 1) *facing* 56
38. Claudel-Hobson Petrol Jet 57
39. Sectional Drawing of Zenith Carburettor (Plate 2) . . . . *facing* 57
40. Arrangement of Zenith Carburettors for Aviation Work (Plate 3) *facing* 58
41. Zenith Carburettor fitted to a Vee Engine (Plate 4) . . . . *facing* 59
42. Arrangement of Jets in the Zenith Carburettor 57
43. Outside view of a High-tension Magneto 62
44. End View of a High-tension Magneto showing High Tension Distributor and Low-tension Contact Breaker 63

ILLUSTRATIONS

FIG. PAGE

45. Sketch of a Sparking Plug 65
46. Diagram to illustrate the Generation of an Electromotive Force by a Magneto Machine 66
47. Diagram to illustrate the self-induction of the Armature Windings . . 66
48. Diagram of Electrical Connections for a High-tension Magneto Machine . 67
49. The 90 H.P Beardmore Aero Engine (Plate 5) . . . . . *facing* 70
50. The 90 H.P. Beardmore Engine from Propeller Boss end (Plate 6) *facing* 71
51. Diagrammatic Section of the Cylinder Head on the Beardmore Aero Engine 71
52. End View of the 120 H.P Beardmore Aero Engine, showing Magnetos and Oil and Water Pump Arrangements (Plate 7) . . . *facing* 72
53. Induction side of the 120 H.P. Beardmore Aero Engine, showing the Arrangement of Carburettors and Valve Gear (Plate 8) . . *facing* 73
54. Exhaust side of 120 H.P. Beardmore Aero Engine, showing the Water Circulation System (Plate 9) . . . . *facing* 74
55. Wolseley 90 H.P. Semi-air-cooled Eight-cylinder Vee Aero Engine, showing the Water Circulating System and Valve Gear (Plate 10) *facing* 75
56. Wolseley 90 H.P. Semi-air-cooled Eight-cylinder Vee Aero Engine, showing arrangement of Tappet Rods, Valve Boxes and Carburettor (Plate 11) . . . . *facing* 76
57. End View of 130 H.P. Wolseley Eight-cylinder Water-cooled Vee Aero Engine, showing arrangement of Carburettor and Induction Pipes (Plate 12) . . . . *facing* 77
58. Wolseley 130 H.P. Eight-cylinder Water-cooled Vee Aero Engine, showing relative position of Valve Boxes on Cylinder Heads (Plate 13) *facing* 78
59. Diagrammatic Section of Air-cooled Cylinder for Wolseley Engines . . 75
60. Aeroplane fitted with the Salmson Engine (Plate 14) . . . *facing* 79
61. Diagrammatic Section of the Cylinder of a Salmson Aero Engine (Canton-Unné System) 79
62. Arrangement of Valve Gear for a Radial or Rotary Aero Engine . . 80
63. Flat Disc, Mushroom Type Valve for Aero Engine 81
64 Stream-line Section, Mushroom Valve for Aero Engine 81
65. Fourteen-cylinder 200 H.P. Salmson Radial Water-cooled Aero Engine, undergoing test, showing Large Propeller and Arrangement of Power Testing Plant (Plate 15) . . . . *facing* 80
66. Nine-cylinder 130 H.P. Salmson Radial Water-cooled Aero Engine on Test (Plate 16) . . . . *facing* 81
67. The 200 H.P. Twenty-cylinder Anzani Radial Air-cooled Engine, showing position of Carburettor (Plate 17) . . . . *facing* 82
68. View showing Method of Fixing the Anzani Engine (Plate 18) *facing* 83
69. The 200 H.P. Anzani Engine fitted with Propeller (Plate 18) . *facing* 83
70. Side view of the 200 H.P. Twenty-cylinder Anzani Radial Air-cooled Aero Engine, showing position of Magneto and arrangement of Valve Gear (Plate 19) . . . . *facing* 84
71. Details of the Anzani Ten-cylinder Radial Air-cooled Aero Engine (Plate 20) . . . . *facing* 85
72. Diagrammatic Sketch to illustrate the working of the Gnome Aero Engine 86
73. 100 H.P. Nine-cylinder Gnome Engine constructed by Messrs. Peter Hooker, Ltd., of Walthamstow, London (Plate 21) . . . *facing* 86
74. Nine-cylinder Gnome Engine (constructed by Messrs. Peter Hooker, Ltd.) with Fuel and Oil Tanks complete ready for test (Plate 22) *facing* 88
75. Nine-cylinder Gnome Engine (constructed by Messrs. Peter Hooker, Ltd.) mounted on the Testing Chassis (Plate 23) . . . . . *facing* 89
76. Master Connecting Rod of the (Hooker) Gnome Engine (Plate 24) *facing* 90
77. Oil Pump fitted on a (Hooker) Gnome Engine (Plate 25) . . *facing* 91
78. Oil-heating Device for the Gnome Engine, constructed by Messrs. Peter Hooker, Ltd., of Walthamstow, London (Plate 26) . . . *facing* 92
79. The 100 H.P. Curtiss Aeroplane Engine, type OX (Plate 26A) . *facing* 93
80. The 200 H.P. Curtiss Aeroplane Engine, type VX (Plate 26B) . *facing* 94
81–82. The 100 H.P. Six-cylinder Mercédès Aeroplane Engine (Plate 26C) *facing* 95

CHAPTER I

The Nature of the Problems

The Function of the Engine

To understand the nature of the problems encountered in the design of aeroplane engines it is necessary to have some elementary notions of the problem of flight in a heavier-than-air machine.

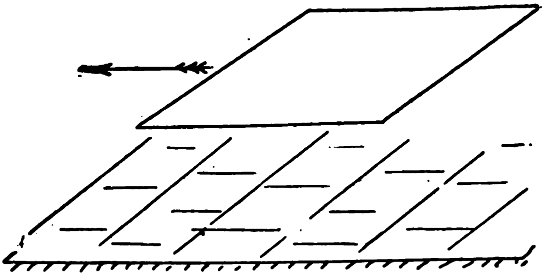


FIG. 1.—Diagram to illustrate Horizontal Motion through the Air.

If we support a thin sheet of cardboard horizontally in the air and then give it a forward push in the direction of the arrow (Fig. 1) it will glide swiftly through the air and float on it for a short distance before falling to the ground. We notice from this simple experiment that very little resistance is encountered to motion through the air provided the moving plane keeps its horizontal position.

The planes of a heavier-than-air machine are, however, slightly tilted upwards, so that as the propeller drives the machine forward the velocity of the air V may be resolved into two components; one V*t* acts along the face of the plane and the other V*n* acts perpendicular to the plane (see Fig. 2).

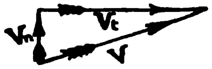


FIG. 2.—Diagram of Wind Velocities.

The component V*t* does no useful work, it merely serves to check the speed of the machine due to friction caused by the passage of the air over the surface of the plane. The component V*n* is the *useful* component.

We can appreciate the effect of V*n* much more readily if we imagine just for a moment that the plane is turned into the vertical position with the component V*n* still acting perpendicular to it. The effect of V*n* is then seen to be the same as would be produced if the plane were held fast in this position, and the wind blew against it with velocity V*n* perpendicular to the face of the plane, as in Fig. 3.

In this case it will be readily understood that the velocity of the wind results in a *wind pressure* being exerted all over the surface of the plane, the cumulative effect of which may be referred to as the *normal pressure* of the wind on the surface of the plane, and is indicated in magnitude and direction by the force P in Fig. 4. The force P may be split up into two component forces *l* and *d*. The component *l* represents that portion of the *normal* wind pressure which *lifts* the aeroplane bodily upwards, while the component *d* opposes the passage of the machine through the air. The thrust of the propeller must be capable of overcoming *d* and also the force of friction caused by the passage of the air across the surface of the planes at a speed represented by V*t* (Fig. 1).

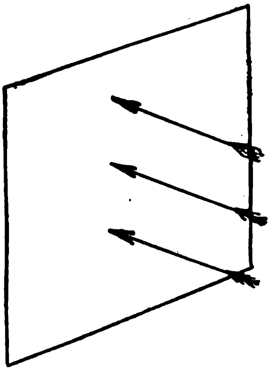


FIG. 3.—Diagram to illustrate the Effect of Wind Pressure.

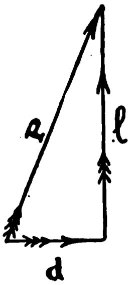


FIG. 4.—Diagram of Forces resulting from Wind Pressure.

Our aim is to study the best means of supplying the motive power to the propeller to enable it to exert the thrust required from it continuously and with unfailing regularity.

It will, of course, be clear that to keep the thrust of the propeller within reasonable limits the weight of the complete machine must be cut down as much as possible, which means that (so far as we are concerned) the engine must have a very low weight per useful horse power developed, i.e. we require a very *efficient* engine.

In general, it may be said that the most efficient engines at present in existence are those which convert the heat energy of fuels into the mechanical energy of rotating shafts. The process of conversion may be either by external combustion or by internal combustion. The internal combustion engine is the more efficient in every respect.

THE EFFICIENCY OF LIGHT INTERNAL COMBUSTION ENGINES

There are three distinct aspects of the word "efficiency" when applied to the performance of petrol or gasoline motors:—

1. *Thermal Efficiency.* This is more in the nature of economy and would be particularly applicable to engines for touring cars and industrial vehicles. A high efficiency engine of this class would be one which gave the greatest power *continuously* for the least petrol consumption. Weight and size are not very important.

2. *Power Efficiency.* This means essentially high *mechanical* efficiency and is particularly applicable to racing engines; it also involves the question of *volumetric* efficiency or the securing

of the maximum power from a given cylinder *volume.* The question of weight must also be considered, but economy in running is of no great importance.

3. *Weight Efficiency.* The questions of economy and power efficiency are both involved in this. The weight of all the engine parts must be kept down to an absolute minimum for the required power, and the weight of fuel and lubricant must also be reduced to the lowest possible limit. This class of engine is required for aeroplanes, hydroplanes, and dirigibles.

Methods of Securing High Efficiency

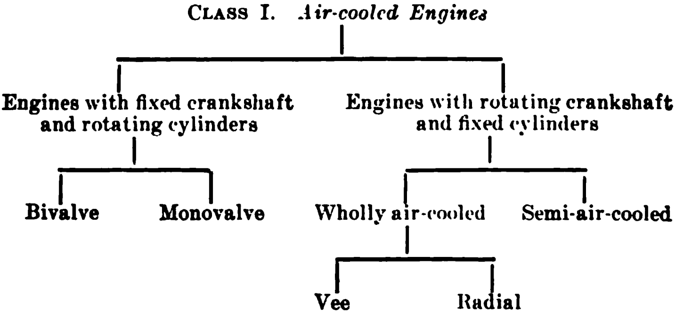
The means by which we are to secure the desired combination of efficiencies will be considered in detail in later chapters principally under the headings of Carburation and Ignition. For the moment we confine our attention to a study of the various forms of areo engines in use at the present time with a view to examining the broad outlines of their general arrangement and the relative advantages which each *class* of engine may be said to possess before investigating the many refinements and details of construction which render each unit, in the estimation of its designers, most qualified to hold the premier place as a motive agent for aeroplanes.

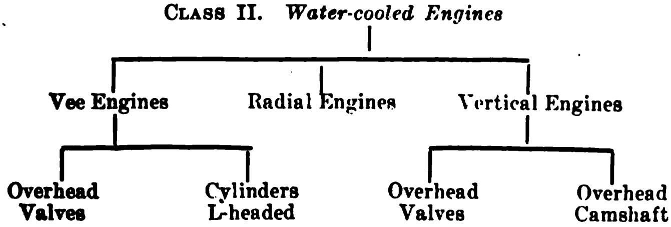
CHAPTER II

Classification of Aeroplane Engines

TYPES OF AEROPLANE ENGINES

THERE are several ways of classifying engines for aeroplane propulsion, but probably one of the best to adopt is to divide them into two principal *classes* each having its own subdivisions, thus:—


CLASS I. *Air-cooled Engines*
Engines with fixed crankshaft and rotating cylinders
Engines with rotating crankshaft and fixed cylinders
Bivalve
Monovalve
Wholly air-cooled
Semi-air-cooled
Vee
Radial



ENGINES OF CLASS I. AIR-COOLED ENGINES

These engines are illustrated diagrammatically in Figs. 5, 6, 7 and 8. In Fig. 5 we show an engine having a fixed crankshaft and rotating cylinders. This type of engine may have one valve or two valves per cylinder, being referred to as a bivalve or monovalve engine accordingly. Typical examples of this class of engine are the Gnome and Le Rhone with two valves, and the Gnome Monosoupape with one valve. In Figs. 6 and 7 we illus-

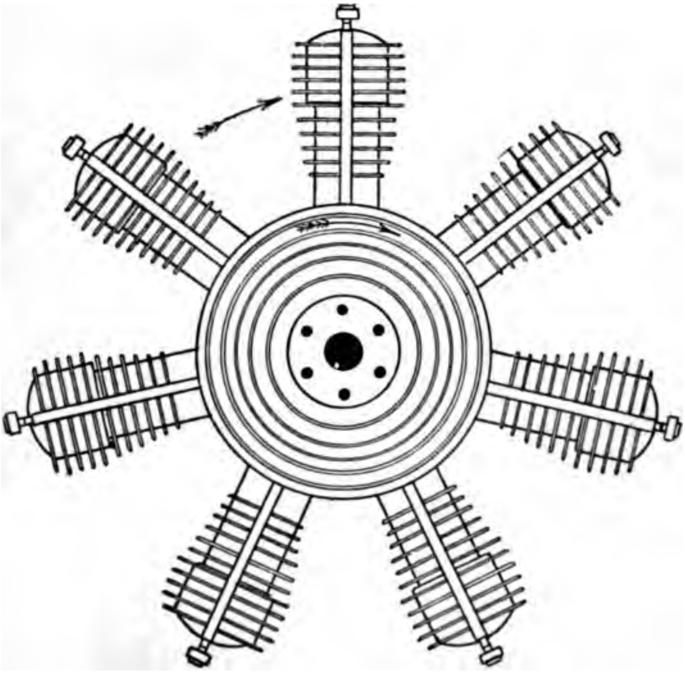


Fig. 5.—Rotary Engine.

trate two engines having fixed cylinders and rotating crankshaft; both engines are of the Vee type, but whereas the one shown in Fig. 6 is wholly air-cooled (like the Renault engine, and other makes) the one shown in Fig. 7 is the Wolseley semi-air-cooled engine with water-cooled exhaust valve. The engine illustrated in Fig. 8 has fixed

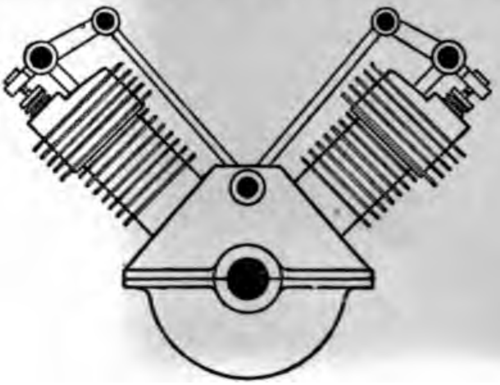


FIG. 6.—Air-cooled Vee Engine.

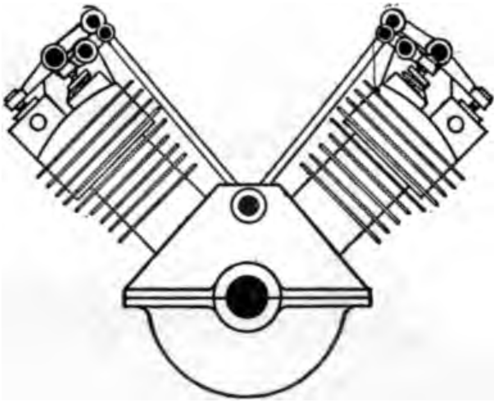


FIG. 7.—Semi-air-cooled Vee Engine.

cylinders arranged radially about a rotating crankshaft and represents the Anzani aeroplane engine.

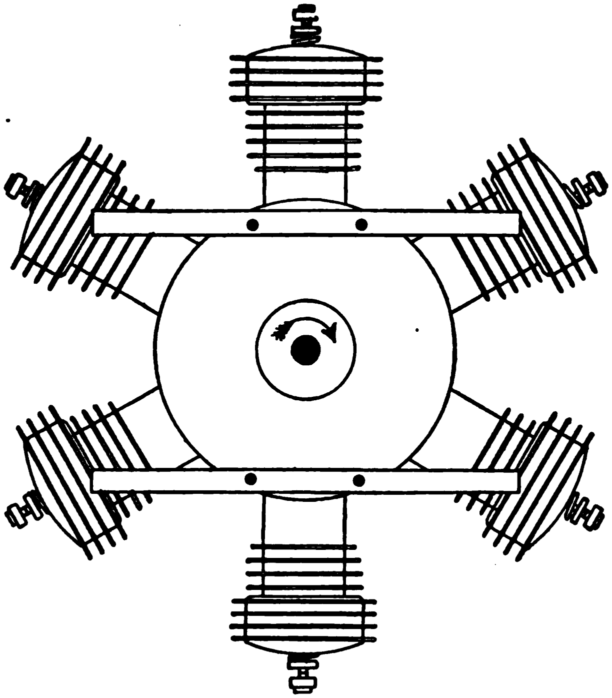


FIG. 8.—Radial Engine, Air-cooled.

ENGINES OF CLASS II. WATER-COOLED ENGINES

These engines are illustrated in diagrammatic forms in Figs. 9, 10, 11, 12 and 13. The vertical engine shown in Fig. 9 is very similar to the ordinary motor-car engine except for the use of the overhead camshaft. This type is constructed by the Green Engine Co. and also represents the

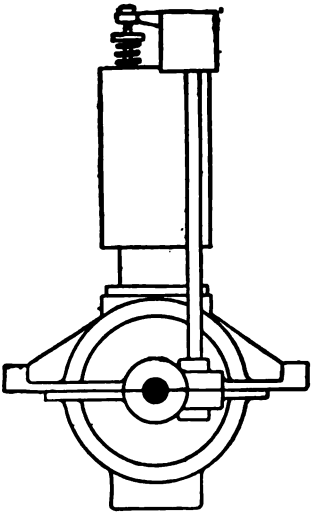


Fig. 9.—Vertical Engine (overhead Camshaft).

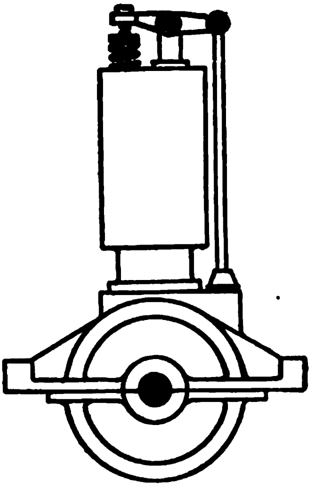


Fig. 10.—Vertical Engi (Long Tappet Rods).

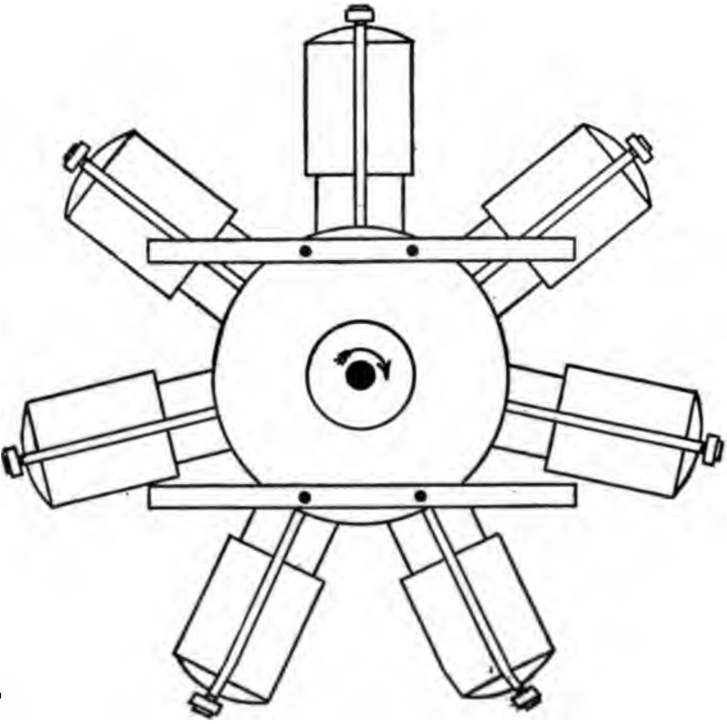


Fig. 11.—Radial Engine (Water-cooled).

Mercedes engine. The Benz and Beardmore-Austro-Daimler are illustrated diagrammatically in Fig. 10 and have long push rods leading from the tappets up to the head of the cylinder. Fig. 11 represents the Salmson radial water-cooled engine with fixed cylinders and rotating crankshaft. In Figs. 12 and 13 we illustrate two water-cooled engines of the Vee type as constructed by Wol-

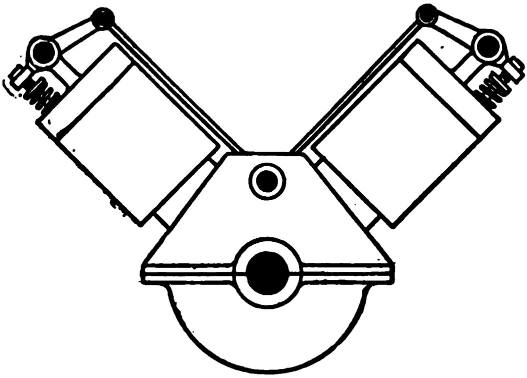


FIG. 12.—Water-cooled Vee Engine.

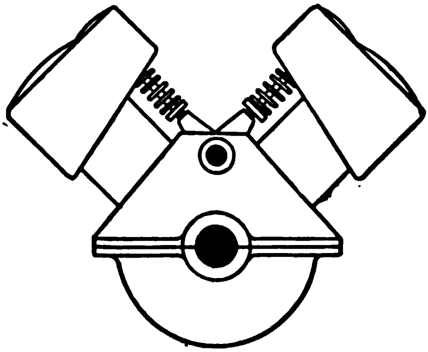


FIG. 13.—Water-cooled Vee Engine (L-headed Cylinders).

seley, Sunbeam, and other firms. Some of these engines have both valves in the positions indicated, and others have the valves arranged one over the other as in Fig. 14.

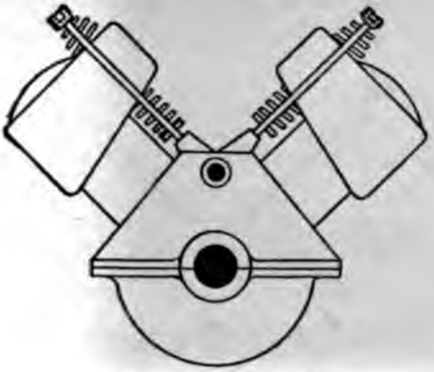


FIG. 14.—Water-cooled Vee Engine.

CHAPTER III

The Relative Advantages of Different Types of Aeroplane Engines

It has been clearly demonstrated by careful experiments that the mean effective pressure obtained in the cylinder of an internal combustion engine is affected considerably by the diameter of the cylinder bore on account of the cooling action of the metal walls, and that the mean effective pressure increases as the bore of the cylinder is made larger. Also one would expect that the dead weight of the engine in proportion to its useful power would decrease in the larger sizes, and this appears to be borne out in practice by the following figures published in the catalogue of the Wolseley Aero Engines:—

TABLE I

Type of Engine.	Bore.	Stroke.	B.H.P.	Speed. R.P.M	No. of Cylinders.	Weight per B.H.P.
Semi-air-cooled	3¾"	5½"	75	1800	8	5.5
Semi-air-cooled	4"	5½"	90	1800	8	4.8
Water-cooled	3¾"	5½"	60	1250	8	6.3
Water-cooled	5"	7"	130	1200	8	5.4

In the same catalogue we find other figures which enable a direct comparison to be made between air-cooling and water-cooling and between high speed and low speed engines as constructed by the Wolseley Tool & Motor Car Co. of Birmingham, but it is not suggested here that these figures represent anything approaching the latest productions of this firm.

TABLE II

Type of Engine.	Bore.	Stroke.	.H.P.	Speed.	No. of Cylinders.	Weight per B.H.P.
Water-cooled	3¾"	5¼"	90	1800	8	4.5
Semi-air-cooled	4"	5½"	90	1800	8	4.4

It will be observed that by adopting water-cooling we are able to obtain a greater power continuously from given cylinder dimensions, but that in this case the reduction in size of the cylinder does not bring the weight of the water-cooled engine down to that of the air-cooled type. The weight of the radiator and water has not been taken into account in this case, but the figures are sufficiently useful to show that a wholly air-cooled engine would be considerably lighter when ready for a flight than the corresponding water-cooled machine.

In considering the speed of rotation of the crankshaft it is important to remember that the power developed by any engine is measured by the product of the torque it exerts and the angular velocity at which its shaft can be turned. The torque of an internal combustion engine is very constant over a wide range of speed, and hence the power of the engine depends very greatly upon the maximum speed at which it can run, i.e. the higher the speed of rotation, the greater the power from a given cylinder volume. We must not forget that the real test of power resolves itself into one of continuity of torque, and this is more likely to be obtained at a relatively low speed than from a very high duty engine. Another factor that must be taken into consideration is the most favourable speed for the propeller, and as this is about 1,200 revolutions per minute gearing must be adopted with high duty engines. The introduction of gearing increases the weight of the engine and reduces the power, but there is, over and above this, a marked saving in weight with a high duty engine as shown by the following figures for the Wolseley aero engines:—

TABLE III

Type of Engine.	Bore.	Stroke.	B.H.P	Speed.	No. of Cylinders.	Weight per B.H.P.
Water-cooled	3¾"	5½"	60	1250	8	6.3
Water-cooled	3¾"	5½"	90	1800	8	4.5

THE ARRANGEMENT OF THE CYLINDERS

Having fixed upon the size of the engine, the speed of rotation, and the system of cooling, the next consideration would be the arrangement and number of cylinders. There are three principal arrangements:—

(1) Cylinders upright and all in one vertical plane.

(2) Cylinders inclined and arranged in two planes to form a Vee.

(3) Cylinders star fashion, and all in the same vertical plane.

In making a selection the table on page 25 may be found useful, but the figures given therein do not refer to any particular make of engine—they are merely representative of modern practice.

VERTICAL AND VEE ENGINES COMPARED

Given two engines with the same number of cylinders and having equal bore and stroke, it will be quite clear that a Vee arrangement is lighter than a Vertical-in-line; but in actual practice we never get such a direct comparison. For equal power output we always find the Vee engines have a greater number of cylinders of smaller bore, the object of this arrangement being to secure greater uniformity of torque by increasing the number of power impulses. As we have already seen, the reduction in size of the cylinder bore increases

TABLE IV

Type of Engine.	Number of Cylinders.	Weight per Horse-Power (Engine only).	Probable Consumption of Petrol per Horse-Power Hour, in Pints.	Probable Consumption of Oil per Hour, in Gallons.	Running Balance for Inertia Forces on Sliding Parts.	Useful Horse-Power.	Speed in Rotation in Revolutions per Minute.
Vertical water-cooled*	6	4.4	0.55	0.3	Perfect primary and secondary balance	100	1300
Vee air-cooled	8	4.0	0.67	1.5	Primary balance only	100	1800
Vee water-cooled*	8	4.1	0.61	0.8	Primary balance only	100	1800
Radial air-cooled	10	3.6	0.70	1.7	No pulsating primary force	100	1250
Radial water-cooled*	7	3.8	0.63	0.5	No pulsating primary force	100	1250
Rotary cylinders (air-cooled)	9	2.8	0.73	2.0	Practically perfect balance	100	1200

* The weight of radiator, piping, and water would be about 0.9 lb. per horse-power.

the weight per horse-power of the engine, and very little saving would result if it were not for the practice of running the Vee engines at a much higher speed than the Vertical-in-line engines; but this also necessitates the use of strong reduction gearing for the propeller drive instead of the usual light timing wheels. There is loss of power in the gearing and an increase of weight due to its use, so that in the end there is not a very great saving in the weight per horse-power of the engine, as is evident from the figures in the above table; but there is a very great saving in the *length* of the engine and a considerable gain in uniformity of turning effort.

Although the actual weights of the parts of a number of aeroplane engines are known to the Author through the courtesy of their designers, it does not seem desirable to publish them at the present time, so that the following figures are to be regarded as estimated weights only. Thus if we put down a few figures to represent the weight of the parts of a 100 horse-power engine they might appear as in Table V, for a vertical-in-line arrangement:—

TABLE V

Description of Parts.	Estimated Weight, lbs.
Cylinders, valves, and valve gear . . .	160
Pistons and connecting rods complete .	50
Camshaft and crankshaft	40
Gearing and all piping	35
Crankcase	55
Flywheel	50
Accessories	30
Total estimated weight . . .	420

Now if this same engine could be arranged in Vee fashion, we would effect only a small saving on the weight of cylinders; valves and valve gear; pistons and connecting rods complete; flywheel, and accessories. There would probably be a little saving in the weight of piping, but the principal saving would be in the crankchamber weight. We might save 35 per cent. of the weight of the crankcase, crankshaft and camshaft, the net saving in the completed engine thus possibly amounting to 10 to 15 per cent. The reduction in length might be 40 per cent. On the other hand, if the cylinders were arranged star-fashion the reduction in weight might be from 20 to 25 per cent. as no flywheel is needed, and in length 70 per cent. These figures assume the speed to be kept the same, and the cylinder dimensions. The reasons why these estimates do not agree with the figures in Table IV are twofold. (1) The usual practice is to use a larger number of smaller bore cylinders for the Vee engine. (2) The reduction in weight will depend upon the discretion of the designer.

The crankcase of a radial or rotary engine is generally larger in diameter than that of the corresponding Vee type engine, and the cam discs are very much larger; also we frequently find an increased length of piping.

It is very interesting to draw up a table illustrating the estimated complete weight of the power plant when ready for a four hours' flight.

From the above table it will be seen that economy in running together with durability are much more important than a low weight per horsepower, especially in the case of machines intended for long distance flights.

TABLE VI

Type of Engine.	Dead Weight of Engine, Piping, and Accessories.	Estimated Weight of Oil and Petrol.	Gross Weight (excluding Tanks).	Gross Weight per Horsepower.
	lb.	lb.	lb.	lb.
Vertical water-cooled*	530	209	739	7.4
Vee air-cooled	400	295	695	7.0
Vee water-cooled*	500	240	740	7.4
Radial air-cooled	360	314	674	6.7
Radial water-cooled*	470	244	714	7.1
Rotary cylinders (air-cooled)	280	335	615	6.1

* Includes radiator and piping.

CHAPTER IV

Choosing the Number of Cylinders

THERE are two important factors which determine the most desirable number of cylinders for a given power output, viz.—

(1) The distribution of the firing impulses imparted to the propeller shafting.

(2) The balancing of the sliding parts of the engine.

DISTRIBUTION OF FIRING IMPULSES

In the present chapter we deal with the distribution of the firing impulses, leaving the balancing to be dealt with in the following chapter.

All the engines which we will consider operate on the four-stroke cycle, that is to say, the cycle of operations is completed once in every four strokes made by the piston, as follows—

1. *The Suction Stroke.* On the first down stroke made by the piston a suction effect or partial vacuum is produced in the cylinder. The cam opens the inlet valve and air is drawn up through the carburettor, filling the engine cylinder with a mixture of air and petrol vapour. The inlet

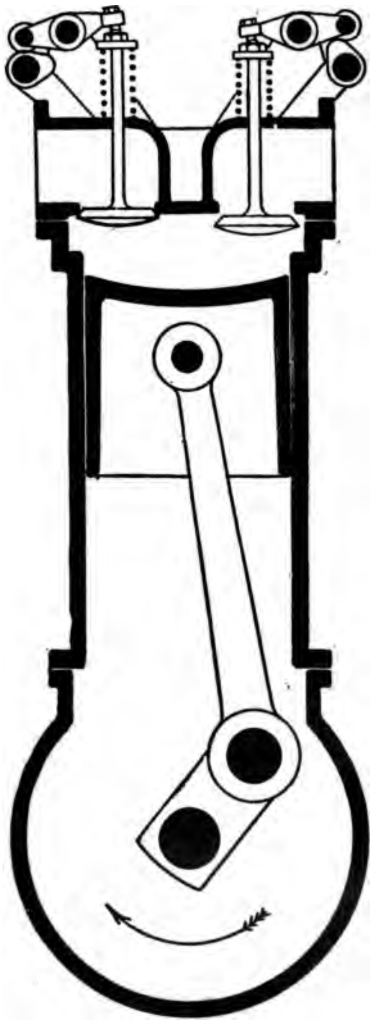


FIG. 15.—Suction Stroke.

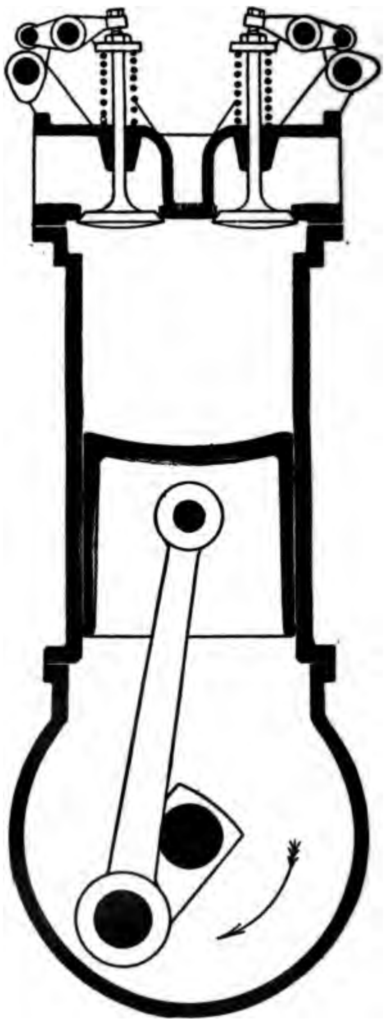


FIG. 16.—Compression Stroke.

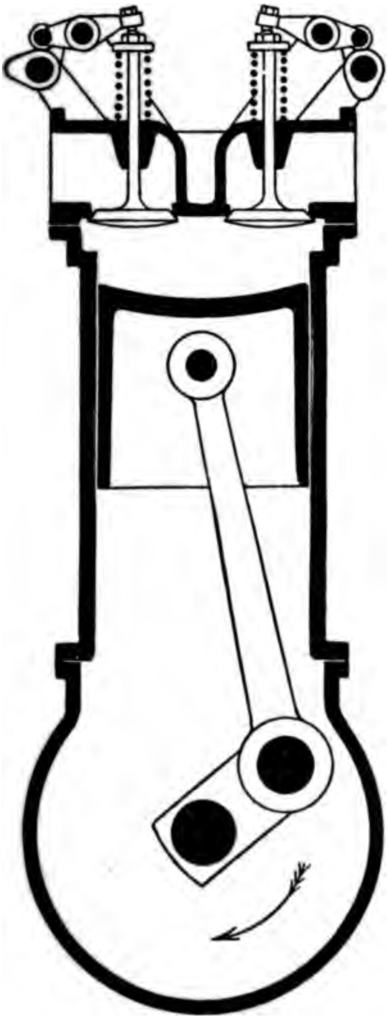


FIG. 17.—Explosion Stroke.

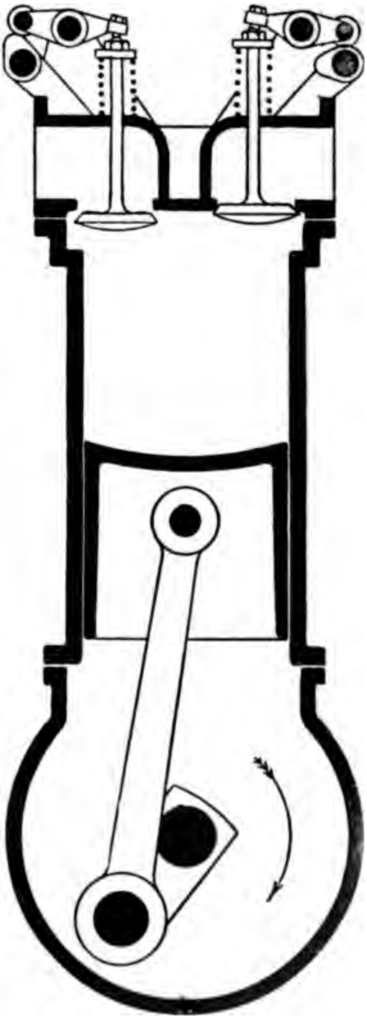


FIG. 18.—Exhaust Stroke.

valve is then closed. This operation is indicated in Fig. 15.

2. *The Compression Stroke.* On the first up stroke made by the piston the charge of explosive mixture is compressed ready for firing. Both valves are shut, as in Fig. 16.

3. *The Explosive Stroke.* Just before the commencement of the second down stroke the charge is fired by a spark from the sparking plug, and the piston is thus driven sharply downwards, doing useful work. This is the power stroke. Both valves are shut. The exhaust valve opens towards the end of this stroke. The operation is indicated in Fig. 17.

4. *The Exhaust Stroke.* As the piston makes its second up stroke it pushes the burnt products of the previous explosion out through the exhaust valve into the atmosphere, as indicated in Fig. 18.

The exact timing of the valves for the operations of inlet and exhaust of gases varies considerably with the type of engine and the judgment of the designer. In some engines the inlet valve opens before the crank reaches its top dead-centre, but in others it remains closed until the crank has passed over the dead-centre. The object in opening early is to secure a full charge, whereas in opening late we aim at better scavenging of the cylinder. Similarly, the exhaust valve may not close until after the crank has passed its top dead-centre, but it is always opened early in the firing stroke. The inlet valve generally closes after the piston has moved a short way up on the compression stroke so that the momentum of the incoming gases may assist the charging of the cylinders. Perhaps an average valve setting for an aeroplane engine would be:—

Exhaust closes and inlet opens when the crank is on its top dead-centre. Exhaust opens when the crank is 60° *from its bottom dead-centre and inlet closes when the crank has moved* 40° *up on the compression stroke.*

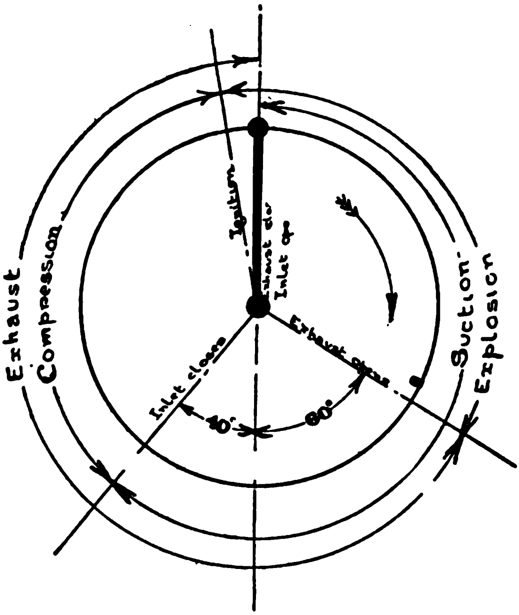


FIG. 19.—Diagram of Valve Setting and Ignition Timing.

This setting is shown diagrammatically in Fig. 19. If we remember that the four strokes of the cycle occur in the following sequence: Suction, Compression, Explosion, Exhaust, we can readily predict the firing order of the cylinders of any type of engine.

VERTICAL AND VEE ENGINES

The easiest case to consider is a four-cylinder-in-line engine with cranks at 180°, as shown diagrammatically in Fig. 20. Supposing No. 1 cylinder has just fired and the crankshaft turns in the direction of the arrow:— Write down the cycle of operations for each cylinder in tabular form as shown in Table VII.

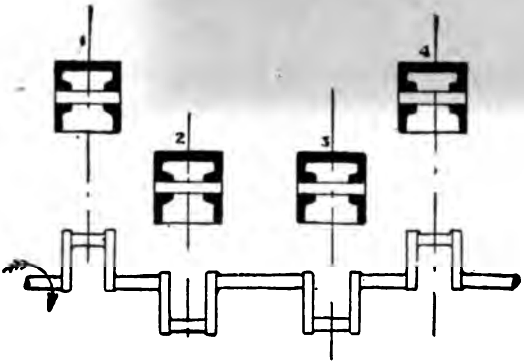


FIG. 20.—Diagrammatic Sketch showing arrangement of Pistons and Cranks in a Four-cylinder-in-line Engine.

Commencing with No. 1 cylinder, we write "EXPLOSION," and then turning to No. 2 cylinder we notice that as the crank turns both No. 2 and No. 3 pistons come up to the top of their respective

TABLE VII

Cylinder Number.	1	2	3	4
Operation	(1) EXPLOSION	COMPRESSION	EXHAUST	SUCTION
	Exhaust	(2) Explosion	Suction	Compression
	Suction	Exhaust	Compression	(3) Explosion
	Compression	Suction	(4) Explosion	Exhaust

cylinders, and hence the designer may select either for the next explosion. If he selects No. 2 to fire next, then it must at the moment be compressing, and No. 3 must *à fortiori* be exhausting, while No. 4 is drawing in a new charge. All we have to do now is to fill in the remaining events of the cycle for each cylinder and we automatically get the correct firing order as 1, 2, 4, 3. It will, of course, be quite clear that there is an alternative firing order, viz. 1, 3, 4, 2, but for our purpose it is sufficient to illustrate one only. An eight-cylinder Vee engine of the type shown in Fig. 14 having two sets of four cylinders inclined at 90° to each other will give four impulses per revolution to the crankshaft as one pair of cylinders in each group will yield a firing impulse during one turn of the shaft.

One method of arranging the firing order for a six-cylinder-in-line engine would be worked out as follows, by reference to Fig. 21. Assuming No. 1

cylinder has fired, it is evident that either 2 or 5 may fire next, and these will be followed by either 3 or 4, thus giving four different firing sequences. If we select No. 2 to fire after No. 1, then during the first half revolution of the shaft No. 1 fires and expands its charge, No. 2 compresses and fires, No. 4 finishes suction and begins compression if it is to fire after No. 2, and Nos. 3, 5 and 6 can then be readily settled because they must be performing some operation which lags 360 degrees behind Nos. 1, 2 and 4 respectively. Then completing the schedule as in Table VIII we get the firing order as 1, 2, 4, 6, 5, 3.

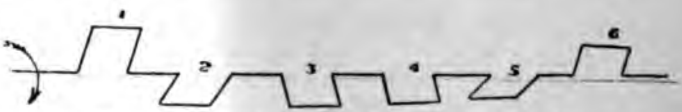


FIG. 21.—Diagram of Crankshaft of Six-cylinder Engine.

ENGINES WITH ROTATING CYLINDERS

We can readily show that it is impossible to obtain regular firing impulses with an engine of this type unless the number of cylinders is odd. Taking the six-cylinder arrangement shown diagrammatically in Fig. 22 first of all:— Each cylinder will fire as it passes across the vertical centre line 1.4, the crank AB being fixed; but if it is not required to fire, then it must be finishing exhausting and beginning compression. As each cylinder only fires once in every two revolutions

TABLE VIII

Cylinder Number		1	2	3	4	5	6
Operation	(1st half revolution)	Explosion	Compression and Explosion	Expansion and Exhaust	Suction and Compression	Exhaust and Suction	Suction
	(2nd half revolution)	Exhaust	Expansion and Exhaust	Exhaust and Suction	Compression and Explosion	Suction and Compression	Compression
	(3rd half revolution)	Suction	Exhaust and Suction	Suction and Compression	Expansion and Exhaust	Compression and Explosion	Explosion
	(4th half revolution)	Compression	Suction and Compression	Compression and Explosion	Exhaust and Suction	Expansion and Exhaust	Exhaust

it will be clear that the cylinders cannot fire in regular numerical order as 1, 6, 5, 4, 3, 2, nor can they fire alternately if the impulses given to the crankshaft are to be equally spaced, because if we

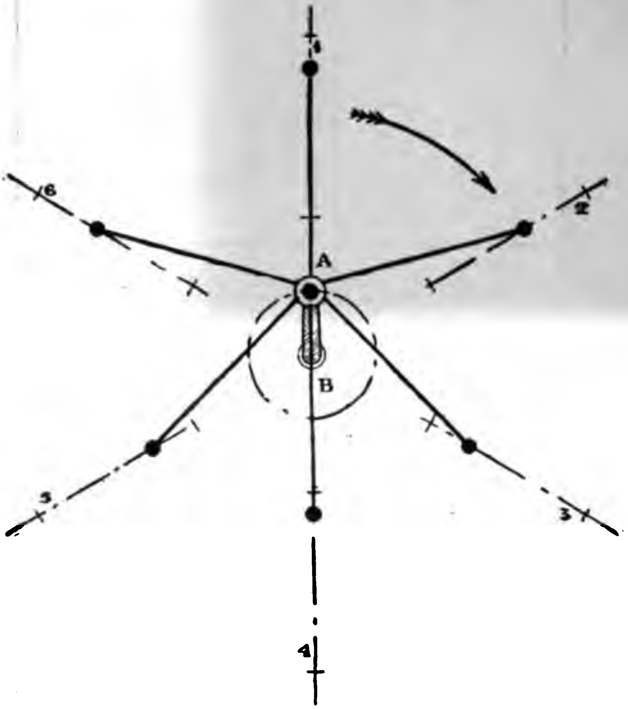


FIG. 22.—Arrangement of Six Cylinders about a Fixed Crankshaft.

select the order, 1, 5, 3, then either No. 2 or No. 6 must fire next, which means intervals of 120°, 120° and 60°, or 120°, 120°, and 180°. If we choose seven cylinders as shown in Fig. 23 they can fire regularly, thus, 1, 6, 4, 2, 7, 5, 3 at equal intervals of $\left(\frac{720^\circ}{7}\right)$ As an illustration we can work this case out on the lines indicated above, the reasoning being simplified because we know the firing order and merely wish to verify it. Arranging the work similarly to the previous case we see

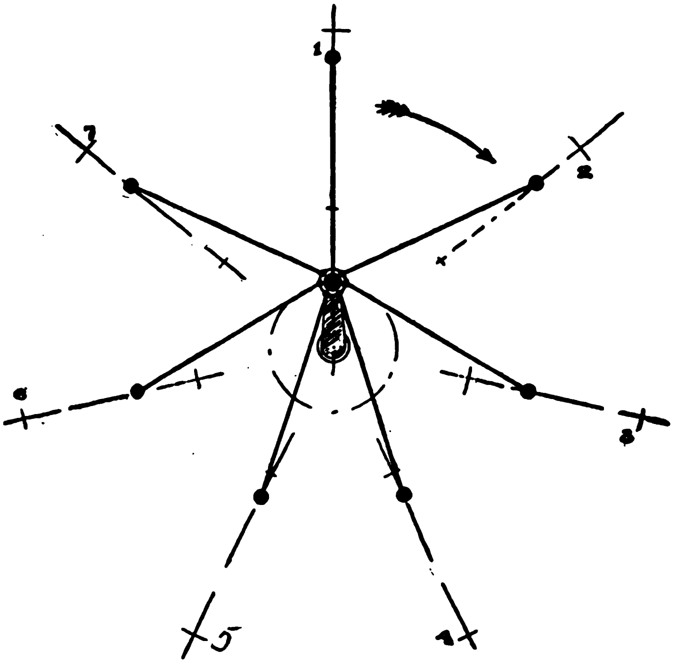


FIG. 23.—Arrangement of Seven Cylinders about a Fixed Crankshaft.

(Table IX) that during the first half revolution No. 1 is expanding, No. 6 is compressing, No. 4 and No. 2 are on their suction stroke, therefore it follows that No. 7 and No. 5 must be exhausting,

TABLE IX

	Cylinder Number	1	2	3	4	5	6	7
Operation	During 1st half revolution	EXPANDING	SUCTION AND COMPRESSION	EXPANDING AND EXHAUST	SUCTION AND COMPRESSION	EXHAUST AND SUCTION	COMPRESSION AND EXPLOSION	EXHAUST AND SUCTION
	During 2nd half revolution	Exhaust	Compression and Explosion	Exhaust and Suction	Compression and Explosion	Suction and Compression	Expansion and Exhaust	Suction and Compression
	During 3rd half revolution	Suction	Expansion and Exhaust	Suction and Compression	Expansion and Exhaust	Compression and Explosion	Exhaust and Suction	Compression and Explosion
	During 4th half revolution	Compression	Exhaust and Suction	Compression and Explosion	Exhaust and Suction	Expansion and Exhaust	Suction and Compression	Expansion and Exhaust

while No. 3 is expanding (having previously fired). Filling in the schedule automatically we obtain the firing order as 1, 6, 4, 2, 7, 5, 3.

RADIAL ENGINES

The case of a radial engine with an odd number of fixed cylinders can be treated in exactly the same way as the rotary cylinder engine given above. A case of special interest however is that

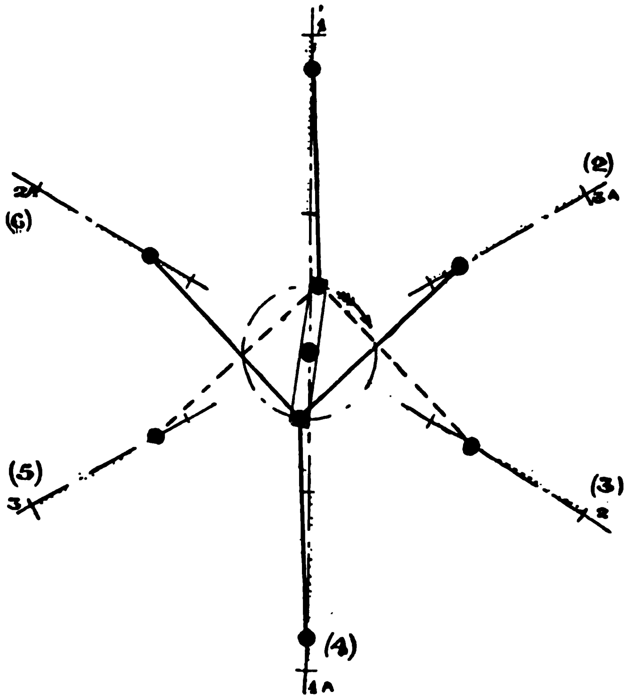


FIG. 24.—Arrangement of six Cylinders in two groups of three Cranks at 180°.

of a radial engine with an even number of cylinders, but having two crankpins 180° apart, e.g. a six-cylinder engine arranged as two sets of three opposing each other in parallel vertical planes, this is shown diagrammatically in Fig. 24. The operations are as follows:—No. 1 fires its charge, and during the first half revolution it expands its charge, while No. 5 and No. 6 are compressing. No. 2 and No. 3 are exhausting and No. 4 is taking in a fresh charge. The remaining events are filled in on the schedule automatically, thus giving the firing order as 1, 6, 5, 4, 3, 2. The effect of this double crank arrangement is twofold: (1) the cylinders fire in regular numerical order; (2) the crankshaft receives firing impulses at equal angular displacements of 120°. This ingenious arrangement is used by the Anzani Engine Co. for their 6, 10 and 20 cylinder aeroplane engines.

TABLE X

Cylinder Number . .		1	2	3	4	5	6
Operation	During 1st half revolution	EXPLOSION	EXHAUSTING	EXHAUSTING	SUCTION	COMPRESSING	COMPRESSING
	During 2nd half revolution	Exhausting	Suction	Suction	Compressing	Explosion	Explosion
	During 3rd half revolution	Suction	Compressing	Compressing	Explosion	Exhaust	Exhaust
	During 4th half revolution	Compressing	Explosion	Explosion	Exhaust	Suction	Suction

CHAPTER V

Balancing the Sliding Parts of the Engine

An investigation of the balancing of the sliding parts of an engine resolves itself into a study of the inertia forces acting on the piston. Every body possesses *inertia*, in virtue of which it offers resistance to any change in its state of rest or uniform motion in a straight line. The piston of an engine has to be brought to rest at the beginning and end of its stroke, but towards the centre of its stroke it is moving at a very high velocity so that large forces are required to overcome its inertia, and these set up corresponding reactions in the framework of the engine. Unless these forces are balanced they will cause disturbances principally in the form of vibrations. The force required to start the sliding parts off from rest and the force which they exert on the frame when coming to rest is measured by the equation $F = \frac{Ma}{g}$ lb. where M is the mass of the complete piston with rings and gudgeon pin, together with about one-third of the connecting rod weight, a is the required acceleration and g is the acceleration due to gravity.

Motion of the Piston of an Ideal Engine

When a particle is rotating in a circular path with uniform angular velocity as indicated in Fig. 25 its projection on the line AB has simple harmonic motion. The acceleration of a body which has simple harmonic motion is proportional to its distance from the centre of its beat or stroke; thus the acceleration is directly proportional to the distance of the particle from the point C, therefore the acceleration diagram is a straight line DCE such that AD is equal and opposite to BE. Now the force required to give the body this acceleration is (as we have observed) $\frac{Ma}{g}$ but since M and g are constant for any given case it follows that DCE is also a diagram of inertia forces or forces necessary to accelerate the piston. At the beginning of the stroke part of the pressure on the piston is required to start the mass off from rest with the required acceleration, this amount

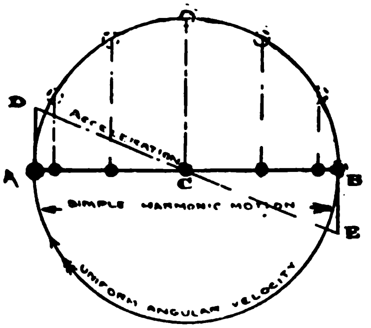


Fig. 25.—Diagram to illustrate *Simple Harmonic Motion.*

being represented by AD to some scale. At the centre of the stroke the acceleration is zero, hence no force is required to move the piston (neglecting friction) and the whole pressure on the piston is available for useful work. At the end of the stroke the piston has to be brought to rest, but since it possesses inertia the mass tends to keep on moving so that its inertia force actually assists the pressure on the piston. The magnitude of the force at the end of the stroke is represented to scale by BE, but since BE = AD the triangle ADC is equal in area to the triangle CBE, so that no work is lost due to inertia. All the energy expended in accelerating the piston is given out again as it comes to rest. Similar reasoning applies on the return stroke of the piston, for which the inertia force diagram is D^1CE^1 (Fig. 26).

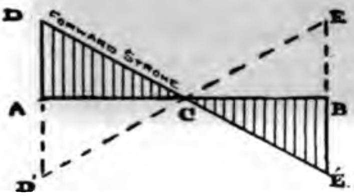


Fig. 26.—Diagram of Inertia Forces acting on the Piston of Air Engine.

MOTION OF THE PISTON OF A PETROL ENGINE

The motion of a petrol engine piston is not simple harmonic motion, unless the connecting rod is infinitely long (so that it can always move parallel to the line of stroke) or unless we have the arrangement sketched in Fig. 27 which is equivalent to an infinitely long connecting rod. Owing to what is known as the *obliquity* of the connecting rod the motion of the piston is not simple harmonic.

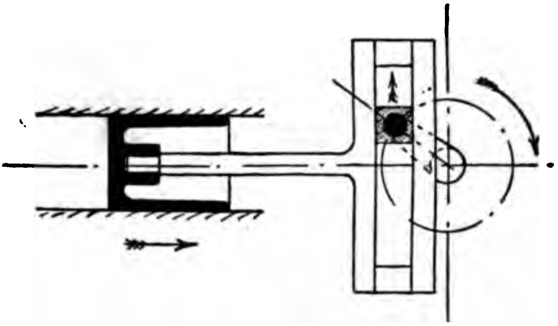


FIG. 27.—Arrangement of Piston and Rod to give Simple Harmonic Motion.

The acceleration of the ordinary piston is not directly proportional to its distance from the centre of its stroke. The discrepancy becomes more marked as the obliquity of the rod increases, i.e. as the ratio $\frac{\text{length of connecting rod}}{\text{length of crank}}$ decreases. With an ordinary piston, and connecting rod of length L feet between centres, with a crank of radius R feet, the following relations may be accepted as accurate enough for nearly all practical purposes:—The inertia force required to accelerate the piston at the beginning of the stroke $=\frac{Ma}{g}\left(1+\frac{R}{L}\right)$ lb. The inertia force exerted by the piston in coming to rest $\frac{Ma}{g}\left(1-\frac{R}{L}\right)$ lb.

The inertia force is not zero when the piston is at the centre of its stroke, but it is approximately zero when the connecting rod is at right angles to the crank. The inertia force for the actual piston is numerically equal to that for the ideal piston when the crank is 45° from either dead-centre. In the above equations $a = 4\pi^2\eta^2R$ when η = revolutions per second of the engine, and $g = 32.2$ feet per second, per second.

TO INVESTIGATE THE BALANCE OF THE SLIDING PARTS OF AN ENGINE

Case I. Engine with Six Cylinders-in-Line

In this case the cranks are arranged in two sets of three, each crank in a set being 120° ahead of its neighbour, as illustrated in Fig. 21 and Fig. 28.

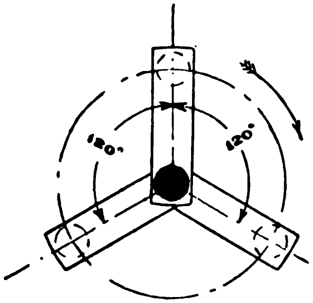


FIG. 28.—Arrangement of Six-crank Engine.

First draw a diagram of inertia forces from the instructions given above by laying down the engine mechanism in outline to scale (see Fig. 29, PLATE 27). The actual diagram of inertia forces is seen to be a curve, and it is very convenient to regard this curve as representing the effects of two sets of imaginary forces, one of which has values exactly equal to what the inertia forces would be if the piston had simple harmonic motion, and the other represents the disturbing effect of the short connecting rod. The first set would be called *primary* inertia forces, and the other set would be called *secondary* inertia forces. It is generally sufficient to test for balance of the primary and secondary forces without considering the other forces brought into action, which are of higher periodicity and smaller magnitude. With the type of engine under consideration we can readily see by scaling off the primary and secondary forces from the diagram that they do actually balance if the masses of the several reciprocating parts are equal. The length AB in Fig. 29 is exactly equal to the sum of the lengths CD and DE, also the length FG is equal to the sum of the lengths HK and KL. From the arrangement of the crankshaft it will also be clear that there are no resultant primary or secondary *couples* tending to twist the engine, so that it is extremely well balanced from the point of view of inertia forces. Another very important consideration is the effect of the forces brought into action on the bearings and crankshaft due to the firing impulses imparted to the pistons. Very often these are more troublesome than the inertia forces, so that they should be very carefully analyzed.

Case II. Engine with Cylinders in the Form of a Vee

There are two cases to consider which are of practical importance at the present time: (1) an eight-cylinder Vee engine with a 90° Vee; (2) a twelve-cylinder Vee engine with a 60° Vee. With a twelve-cylinder Vee engine the cylinders are arranged as two sets of six inclined at 60° to each other, with crank angles of 120°, so that since each side of the Vee has complete primary and secondary balance as shown above, the resulting balance of the two sets is as good as can be obtained; but this is not the case with the eight-cylinder Vee engine arranged as two sets of four cylinders inclined at 90° to each other, with crank angles of 180°. If we lay down the outline of the mechanism of an eight-cylinder Vee type engine we find that the primary forces are balanced on each side

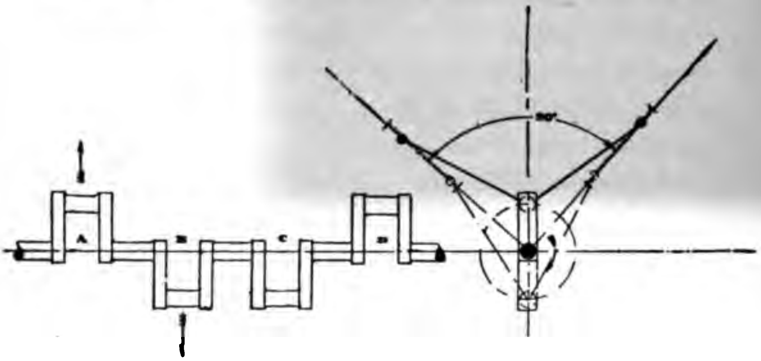


FIG. 30.—Arrangement of Eight-cylinder Vee Engine.

of the Vee, but the secondary forces are not. Considering only one pair of pistons AB on one side of the Vee, the outline of the crankshaft will be as shown in Fig. 30, which gives both the primary force diagram and secondary force diagram of Fig. 31 (PLATE 28). The other pair of cylinders CD will yield a similar result, so that the resultant secondary unbalanced force for one side of the Vee is double that shown on the diagram. Similarly for the other side of the Vee. The joint effect of the two sides is obtained by resolving each of these separate sets of forces vertically and horizontally, when it will readily be ascertained that the maximum value of the unbalanced secondary force is $4\sqrt{2}$ times the maximum secondary force for one piston. Its line of action lies in a horizontal plane passing through the crankshaft bearings, and the force alternates in direction. The vertical components cancel each other. The eight-cylinder Vee is therefore badly out of balance, so far as inertia forces are concerned, but their effect is in practice somewhat toned down by the other forces we have mentioned as arising from the firing impulses on the pistons.

Case III. Engines with Cylinders arranged Radially

The Author has investigated two separate cases: (*a*) an engine having a single crank and seven sets of cylinders all in one vertical plane; (*b*) an engine having two cranks at 180° and ten cylinders arranged in two groups of five. In both cases the primary inertia forces are not balanced, but they yield a resultant which is nearly constant in magnitude (see Fig. 32, Plate **29** and Fig. 34, Plate **31**). In case (*a*) this large unbalanced primary force would become a pressure moving half-way round the main bearings with the crank and then returning against it, the magnitude of the pressure being very considerable, but least towards the centre of its traverse (see Fig. 32, Plate **29** and Fig. 33, Plate **30**). The secondary forces are in comparison negligible. In case (*b*) the resultant unbalanced primary inertia force for each set of pistons is constant in magnitude, but, as above, travels half-way round the bearings and then returns (see Fig. 34). Owing to the fact that the second crank is 180° ahead of the first the resultant unbalanced primary inertia force for the second group of cylinders would exactly balance the first if it were not for the fact that the two groups are of necessity slightly displaced laterally so that the two forces form a couple. The resultant unbalanced couple is therefore comparatively large and the effect of the secondary forces is again small. With both types of engine the pressure on the bearings may be (and actually is) materially modified by the pressures due to the firing impulses imparted to the pistons. In practice therefore with both types of engine the effect of the inertia forces might easily be of secondary importance.

Case IV. Engine with Rotating Cylinders

In this case we have two sets of masses rotating about two independent fixed centres viz. the crankshaft and the crankpin. The cylinders are obviously perfectly balanced if the masses are all equal. The outline of the mechanism for a nine-cylindered Gnome engine is illustrated in Fig. 35, which shows that the pistons and connecting rods

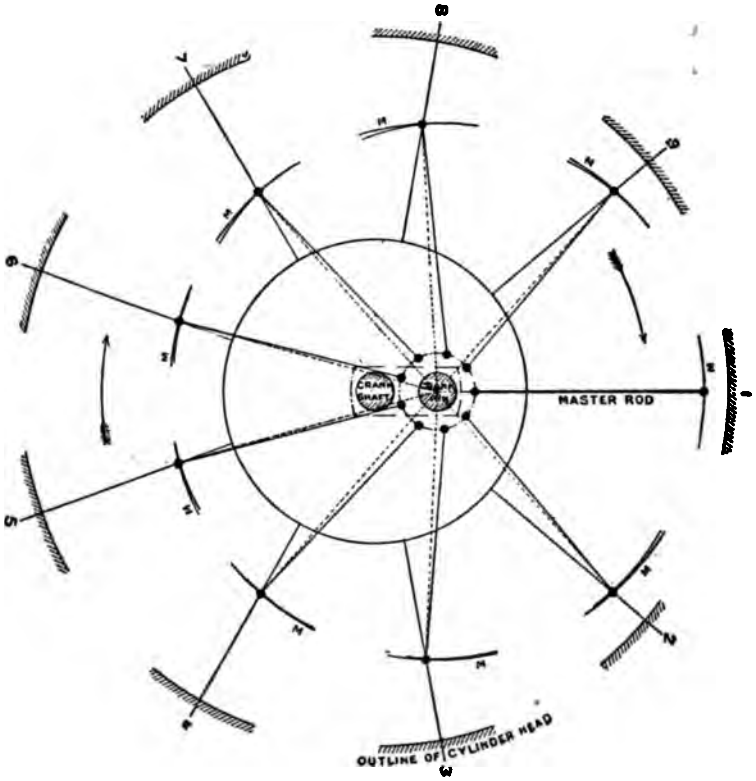


FIG. 35.—Nine-cylinder Gnome Engine.

are very nearly balanced; the only disturbing factor, the obliquity of the rods, is very small indeed. We are therefore justified in describing this type of engine as perfectly balanced, so far as inertia forces are concerned. We must, however, again emphasize that the effect of the firing impulses has not been considered.

CHAPTER VI

Carburation

A CARBURETTOR is a contrivance for supplying an explosive mixture of air and petrol vapour to a petrol engine. At the present time there are only two carburettors in general use for aviation work: (1) the Claudel-Hobson and (2) the Zenith. In both these carburettors the float chamber is of the usual pattern, containing a hollow metal float which pushes a needle valve down on to its seating and automatically stops the inflow of petrol to the jet as soon as the liquid in the chamber has risen to a height corresponding to the jet orifice. When petrol is being drawn off at the jet by the suction of the engine the level in the chamber tends to fall, and thus the float releases the needle valve and allows more liquid to enter and correct the level. The orifice at the top of the petrol jet is made very small so that the liquid will be sprayed and thus readily vaporized. With a powerful engine so much petrol is required from the jet that the orifice necessary is too large for successful spraying, and the stream of petrol issuing from the jet should be atomized after leaving the orifice; this forms the essential feature of the

Claudel-Hobson carburettor. To ensure a proper suction effect being exerted upon the jet at low

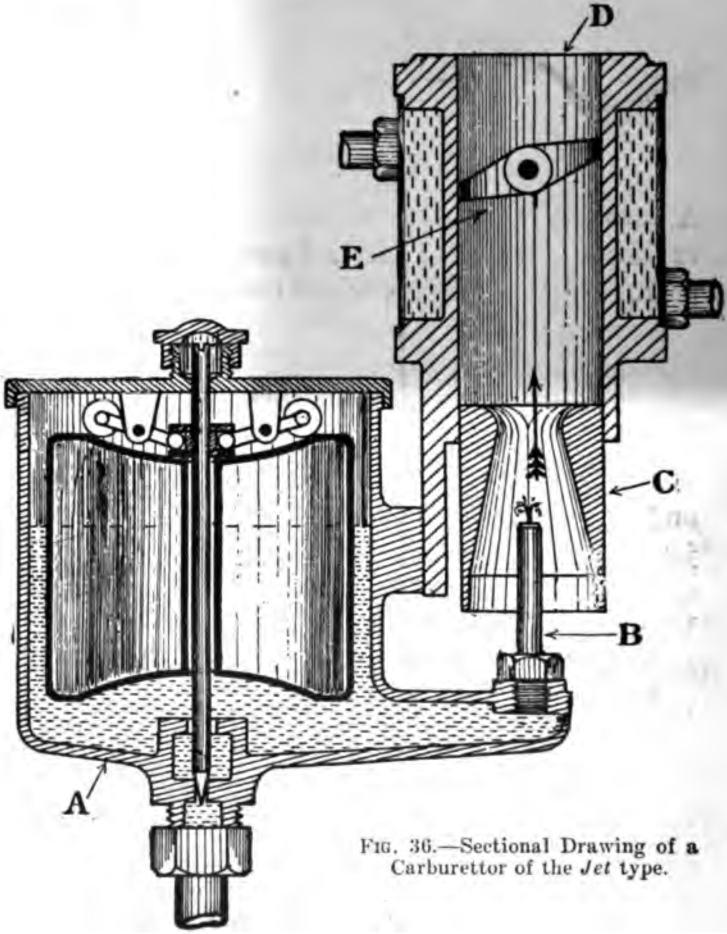


FIG. 36.—Sectional Drawing of a Carburettor of the *Jet* type.

engine speeds as well as at high engine speeds the jet is surrounded by a small diameter tube, termed the choke tube, which may be either taper or par-

PLATE 1.

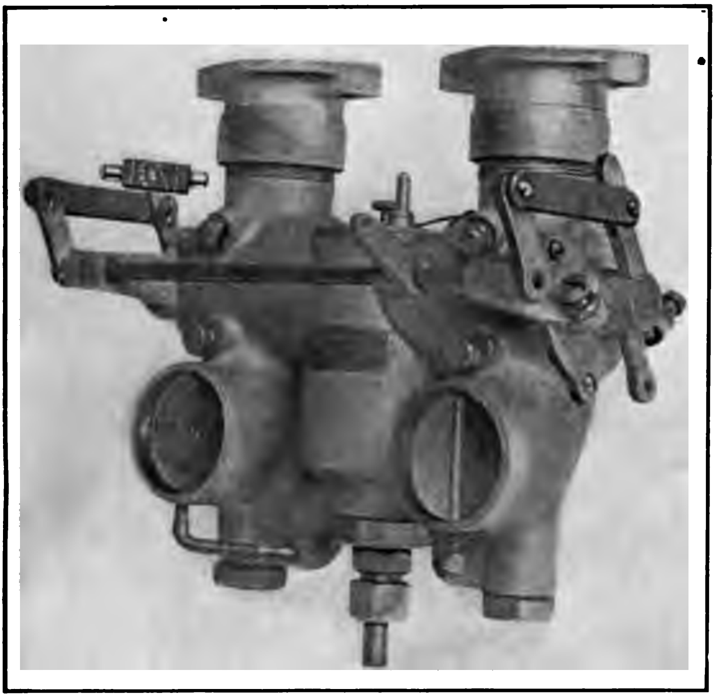


FIG. 37.—Claudel-Hobson Carburettor as arranged for Aviation Work.

To face p. 56, KEAN, AERONAUTICAL ENGINES.]

PLATE 2.

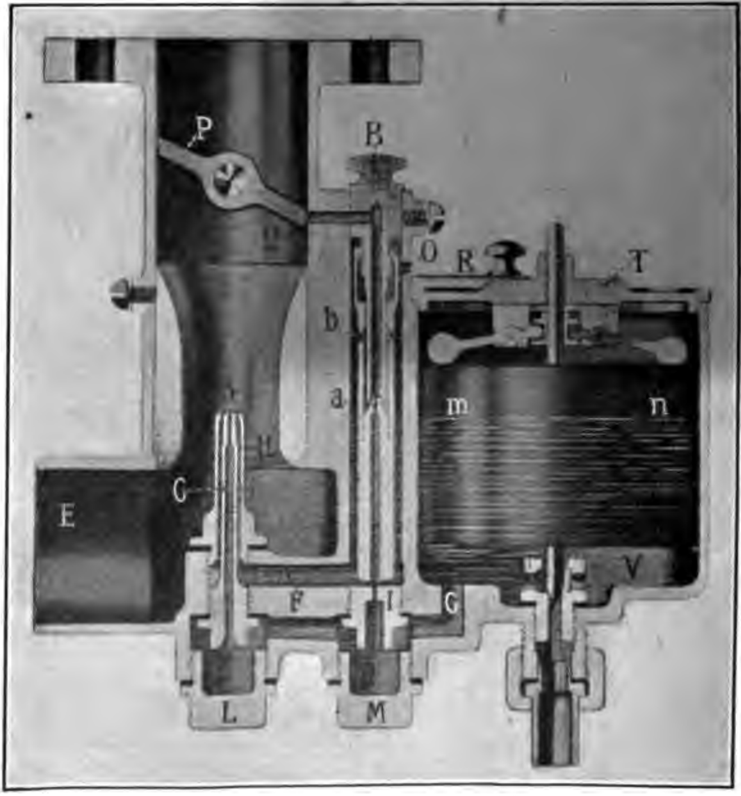


FIG 39.—Sectional Drawing of Zenith Carburettor.

allel in the bore. It is found, as a rule, that if the choke tube is proportioned to draw the correct quantity of petrol from the jet at low speeds it will draw too much (in proportion to the air admitted) at high speeds unless some form of compensating device is fitted; this forms the essential feature of the Zenith carburettor. A simple carburettor is shown in Fig. 36 in which A is the fl chamber, B is the petrol jet, C is the choke tube, D is the mixing chamber, E the throttle valve, F the float, and G the needle valve. The mixing chamber is surrounded by a hot-water jacket to supply the heat necessary to completely vaporize the petrol at all atmospheric temperatures. The Claudel-Hobson carburettor as used for aviation

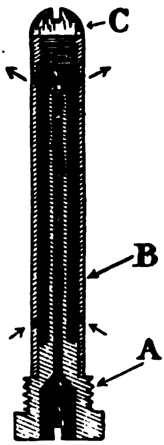


FIG. 38.—Claudel-Hobson Petrol Jet.

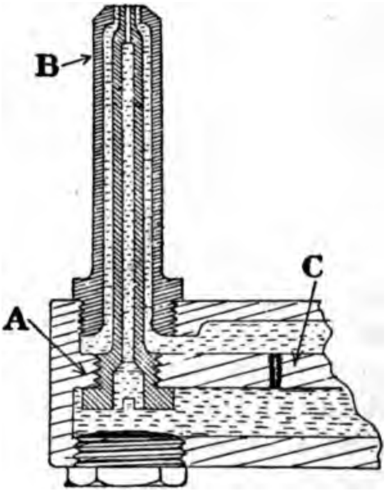


FIG. 42.—Arrangement of Jets in the Zenith Carburettor.

work is shown in Fig. 37, which is reproduced by kind permission of Messrs. H. M. Hobson, Ltd., and the atomizing jet is illustrated in Fig. 38. It will be seen from this sectional sketch that the petrol jet has no special orifice, but is surrounded by another tube B containing small holes for the inflow of air and outflow of petrol. As the petrol issues from the jet it strikes against the pointed end of the screw C and is thus very successfully atomized and broken into small particles which can be readily vaporized. The Zenith carburettor is shown in Figs. 39, 40 and 41, which are reproduced by kind permission of the Zenith Carburettor Company. The principle of the compensating jet may be explained thus, by reference to Fig. 42. The main jet A is of sufficient size to supply the requirements of the engine under full speed and with the resulting high vacuum in the choke tube; it is fed directly from the float chamber in the usual manner. The compensating jet B surrounds the main jet and is supplied with petrol from an orifice which is indicated by C. The orifice is so proportioned that it offers a greater resistance to flow than the passage up the centre of the main jet. At all engine speeds up to a predetermined maximum the compensating jet will supply most of the petrol, but as the demand increases the main jet will also begin to supply under the increased suction, and simultaneously the compensating jet will commence to go out of action owing to failure of its supply, thus prevent-

PLATE 3.

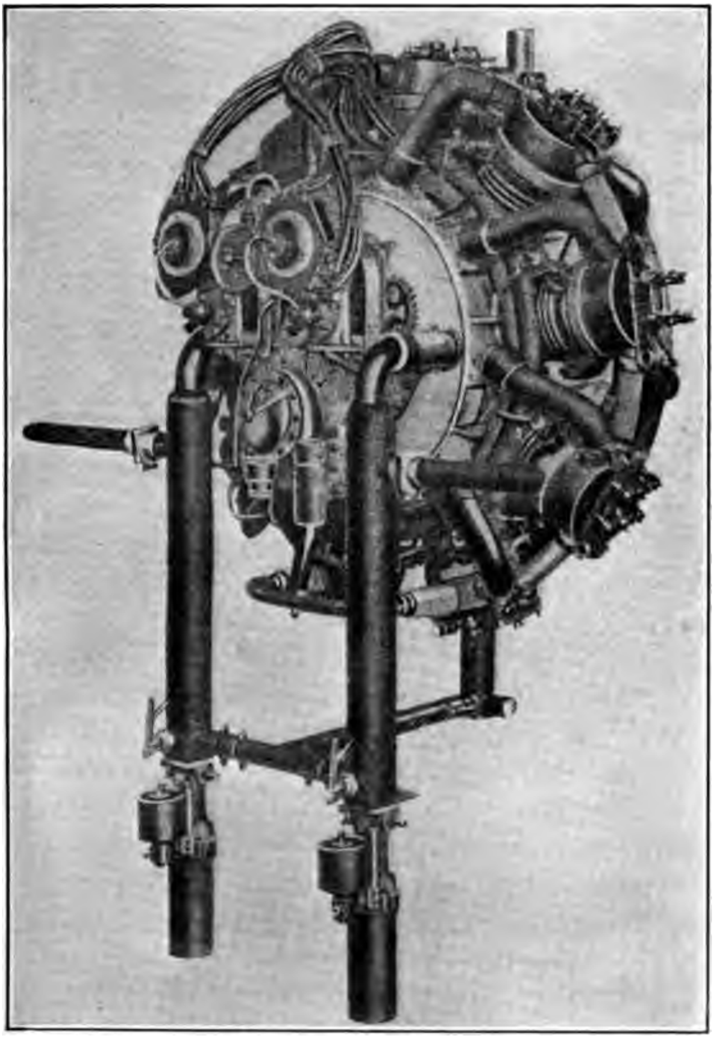


FIG. 40.—Arrangement of Zenith Carburettors for Aviation Work.

To face p. 58, KEAN, AERONAUTICAL ENGINES.]

PLATE 4.

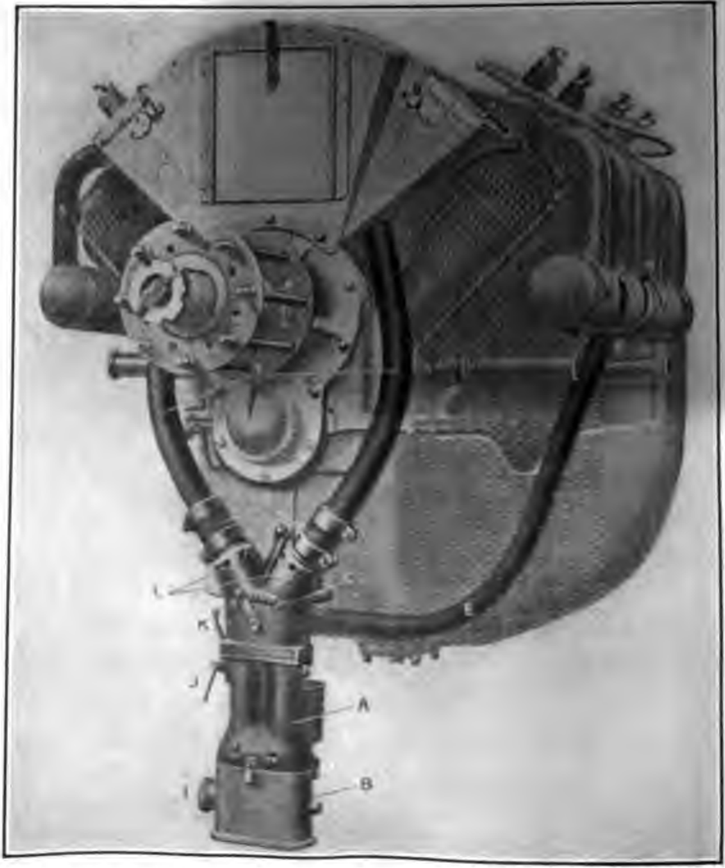


FIG. 41.—Zenith Carburettor fitted to a Vee Engine.

ing an excessively rich mixture. A good deal of light may be shed upon many carburation problems which at present appear obscure by a study of the results of some researches carried out by the Author with the assistance of his students at the Regent Street Polytechnic (London, W.) and published in *The Engineer* during May, 1915.

The results may be summarized and explained thus:—

(1) A relatively weak mixture of about 17 lb. of air per 1 lb. of petrol vapour gives the greatest thermal efficiency and the least petrol consumption.

(2) The weaker the mixture becomes the higher is the temperature of the exhaust gases; the power falls off and the heat lost to the jacket water becomes less.

(3) A mixture slightly richer than the theoretically correct one (15 lb. of air per 1 lb. of petrol vapour) which corresponds to about 14½ lb. of air per 1 lb. of petrol vapour gives the greatest power and rejects most heat to the jacket water, but the thermal efficiency and petrol consumption are not so good as with the weaker mixture cited above. The temperature of the exhaust gases becomes lower as the strength of the mixture increases.

(4) When the mixture is very rich the power quickly falls off and the thermal efficiency gets very low. The fuel consumption is excessive, less heat is rejected to the jacket water, and the tem-

perature of the exhaust gases falls off. Carbon deposit becomes evident on cylinder heads, pistons, valves, and sparking plugs.

EXPLANATION OF THE RESULTS

When the mixture is slightly *too weak* there is an excess of air present in the cylinder over that required for complete combustion of the fuel, and hence we are certain to get the fuel completely burned; but it follows of course that the actual *weight* of fuel burnt is not so great as it might be, and hence we do not obtain the greatest power from the engine. As the mixture becomes weaker it ignites less readily and combustion is slower, so that the charge may be in an incandescent state when it passes out to the exhaust—this explains the rise in the exhaust temperature. When the mixture is about *theoretically correct* combustion is often not quite complete, and therefore although we burn a greater weight of charge in the cylinder and thus develop a greater power the efficiency of the process is not so high. When the mixture is *too rich* we get a larger quantity of petrol than before into the cylinder, but as the air supply is the same or rather less the combustion is imperfect, so that instead of the carbon and hydrogen of the petrol turning to carbon dioxide and steam, some of it appears as carbon monoxide, free hydrogen, and heavy hydro carbons. Therefore it is not difficult to see that the temperature of the exhaust gases may be much lower and less power be developed by the engine. The efficiency of the process is of course very low and the fuel consumption abnormally high.

CHAPTER VII

Ignition

The charge of gas in the engine cylinder is fired by a spark from a high tension magneto machine.

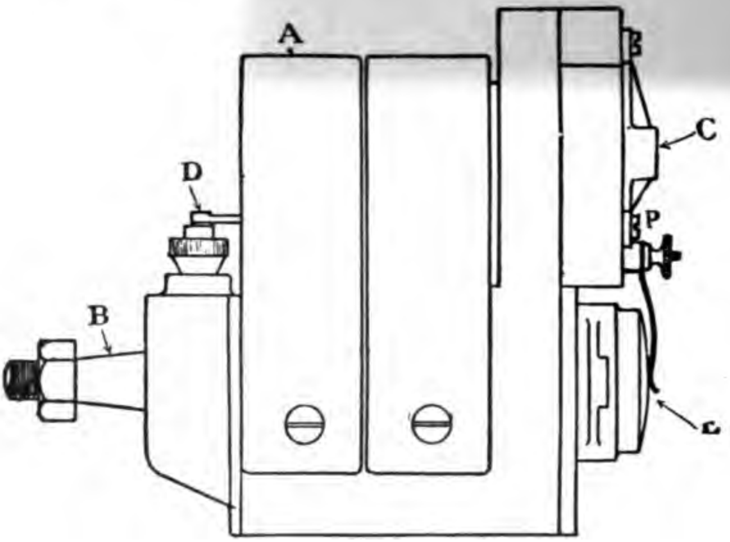


Fig. 43.—Outside View of a High-tension Magneto.

The magneto is driven by gearing from the engine crankshaft, or crankcase (when the crankcase rotates). The essential parts of a magneto of this type are shown in Fig. 43 and Fig. 44 and consist of the stationary magnets A, the driving spindle B, the high tension electrode D, the high tension distributor C, and the low tension contact breaker E. The armature, condenser, and distributor gear wheels are not shown in the draw-

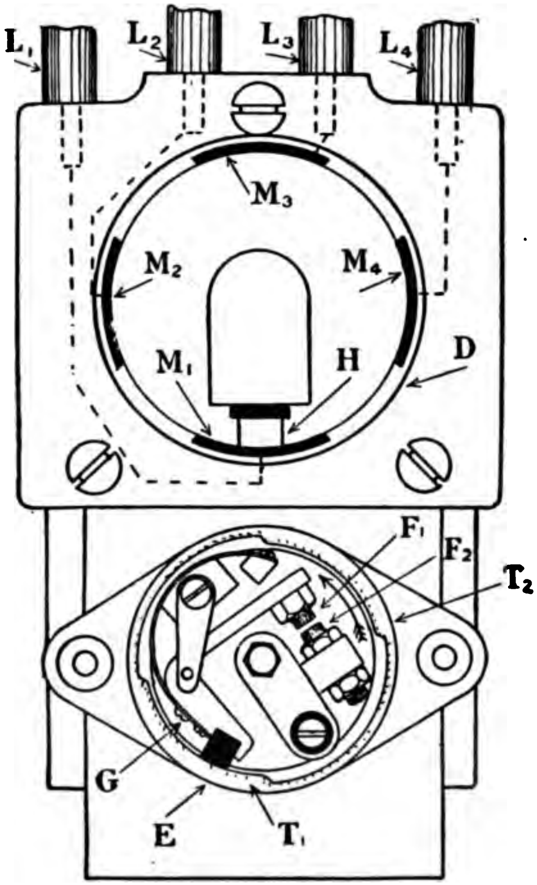


FIG. 44.—End View of a High-tension Magneto showing High-tension Distributor and Low-tension Contact Breaker.

ings, but are situated inside the machine in the space between the high tension electrode D and the low tension contact breaker E. There are two sets of windings on the armature, so that as the spindle B is rotated by the gearing those windings generate a high tension and a low tension current. The high tension current passes to the high tension electrode D and thence across the machine to the carbon brush H of the high tension distributor C. The low tension current passes through the platinum tipped contact screws F_1F_2 of the low tension contact breaker. Twice during each revolution of the armature these contacts are separated owing to the fibre block attached to the bell crank lever G passing over the projections T_1 and T_2; this constitutes the make-and-break device for interrupting the primary current. The momentary interruption of the primary current in this way causes a very great increase in the electrical pressure (or voltage) of the secondary or high tension current which is sufficient to bring about the spark discharge across the gap between the electrodes of the sparking plug. A typical sparking plug is shown in Fig. 45. The high tension distributor consists of the carbon brush H driven by gearing from the magneto armature and the metal segments M_1, M_2, M_3, M_4 which are mounted in a block of insulating fibre. Each metal segment is connected to a sparking plug lead such as L_1, L_2, L_3, L_4. A two-pole machine such as the one illustrated can supply current for two sparks during one revolution of the armature, so that if the distributor has four segments the brush H must be driven at half the armature speed, but if there are six segments the brush must turn at ⅓ the armature speed and so on. The high tension electrode D is attached to a light carbon brush which presses on a gun-metal collector ring at the high tension end of the armature winding. A special terminal is provided at P, so that when a wire is attached to it and connected to the engine frame (usually through a switch) the low tension windings are short-circuited or closed on themselves and the make-and-break has no effect, because there is always a path for the current to continue flowing until the switch is opened again. Under these circumstances the voltage of the high tension circuit is not sufficient to cause the spark discharge, and the ignition is said to be switched off. The instant at which the spark occurs may be advanced, or made earlier, by moving the rocker arm K which carries the projecting pieces T_1 T_2 backwards. If the rocker arm be moved forward, in the direction of rotation of the armature, the ignition is retarded and the spark occurs later in the stroke of the piston. If the magneto was set with the engine sta-

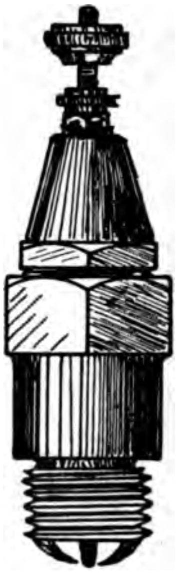


FIG. 45.—Sketch of a Sparking Plug.

tionary so that the spark would occur when the piston was in its highest position the ignition would require to be advanced when the engine was running owing to the time-lag of the current. The condenser is fitted to reduce this time-lag to a minimum. It is impossible to explain the action of a magneto without going into the realm of Electrical Engineering. The space between the poles of a magnet may be regarded as in a state of stress and crossed by what are termed lines of magnetic flux. When a copper wire is made to cut across these lines of flux an electromotive force is generated in the wire, and if the ends of

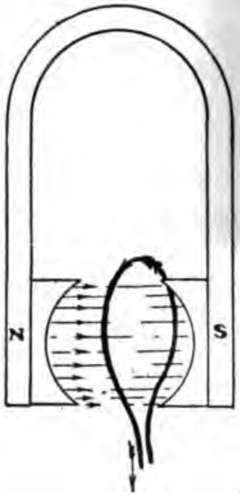


FIG. 46.—Diagram to illustrate the Generation of an Electromotive Force by a Magneto Machine.

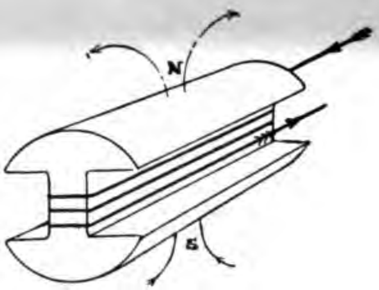


FIG. 47.—Diagram to illustrate the self-induction of the Armature Windings.

the wire are joined (say by the platinum-tipped contact screws) a current flows round the loop; this is indicated in Fig. 46. Again, when a coil of wire carrying a current is wound round an iron core the core becomes a magnet for the time being, as shown in Fig. 47. The electrical connections

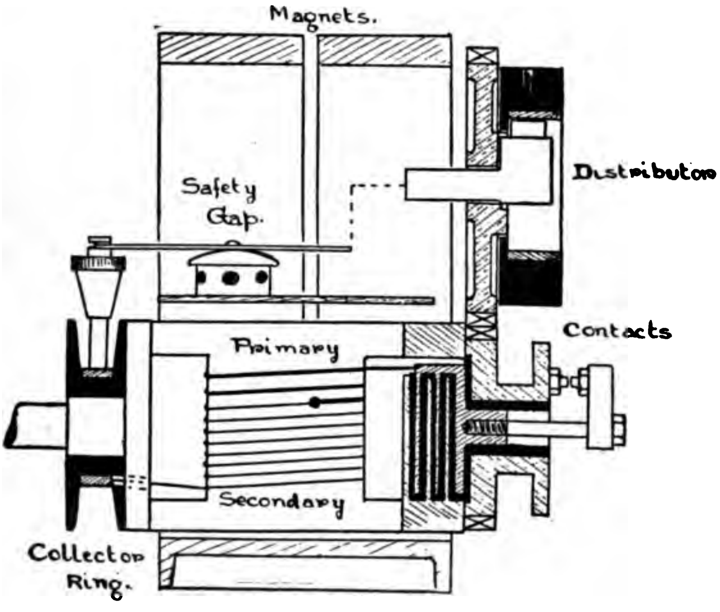


FIG. 48.—Diagram of Electrical Connections for a High-tension Magneto Machine.

for a high tension magneto are shown diagrammatically in Fig. 48. Actually the low tension windings are wound round the core first and consist of a few turns of comparatively thick wire; then the secondary windings are wound over these and consist of many turns of very fine wire. As the driving spindle and armature core are rotated both sets of windings cut the lines of magneto flux, so that each generates an electromotive force. The primary windings may generate at ten volts and the secondary at 1,000 volts when the speed is 1,000 revs. per minute, but this electrical pressure of 1,000 volts is not enough to cause the spark to jump the gap between the electrodes of the sparking plug. When the platinum-tipped screws of the low tension contact breaker are touching each other a current is able to flow in the primary windings, and thus the iron armament core becomes strongly magnetized, due to this. The momentary stopping of the primary or low tension current by the separation of the contacts causes these lines of magneto flux to collapse, and in collapsing they cut through the secondary windings, thus creating a new electromative force in them which is sufficient to raise the voltage of the secondary circuit to say 5,000 volts, and this is enough to cause the spark to pass. Owing to what is known as the "inductance" of the windings due to the presence of the iron core the primary current does not start and stop instantaneously with the movement of the contacts unless a capacity or condenser is fitted across the windings to annul their inductance.

Another very important factor in ignition is the speed of propagation of the flame through the mass of gas in the cylinder after it has been ignited by the spark. Obviously the ideal conditions would be instantaneous propagation, and to achieve this many firms have fitted two-point ignition in which the charge is fired simultaneously from two independent positions in the combustion chamber. It has been shown, however, that owing to the high speed of the piston and the rapidity of the operations of compressing, etc., the gases are in a very turbulent state, so that little if anything is gained by two-point ignition.

CHAPTER VIII

Typical Aeroplane Engines

I. THE BEARDMORE ENGINE

THE Beardmore Aero Engine Co. make two sizes of aeroplane engines, one giving 90 horse-power, and the other 120 horse-power, each having six water-cooled cylinders mounted vertically in line similar to a motor-car engine. The 90 horse-power engine referred to previously in the text is shown in Figs. 49 and 50 and the 120 horse-power engine in Figs. 52, 53, and 54. Engines constructed on the lines of the Beardmore engine have been used by all the principal governments of the world and have in addition gained many prizes and secured many records in flight. Fig. 51 gives a good idea of the internal arrangement of the cylinders, from which it will be observed that the valves are in the head and inclined. Inclining the valves allows a larger diameter to be fitted in a given cylinder bore, and also it facilitates the arrangement of the valve gear. The cylinders are cast separately and surrounded by copper water jackets electrically deposited. The

PLATE 5.

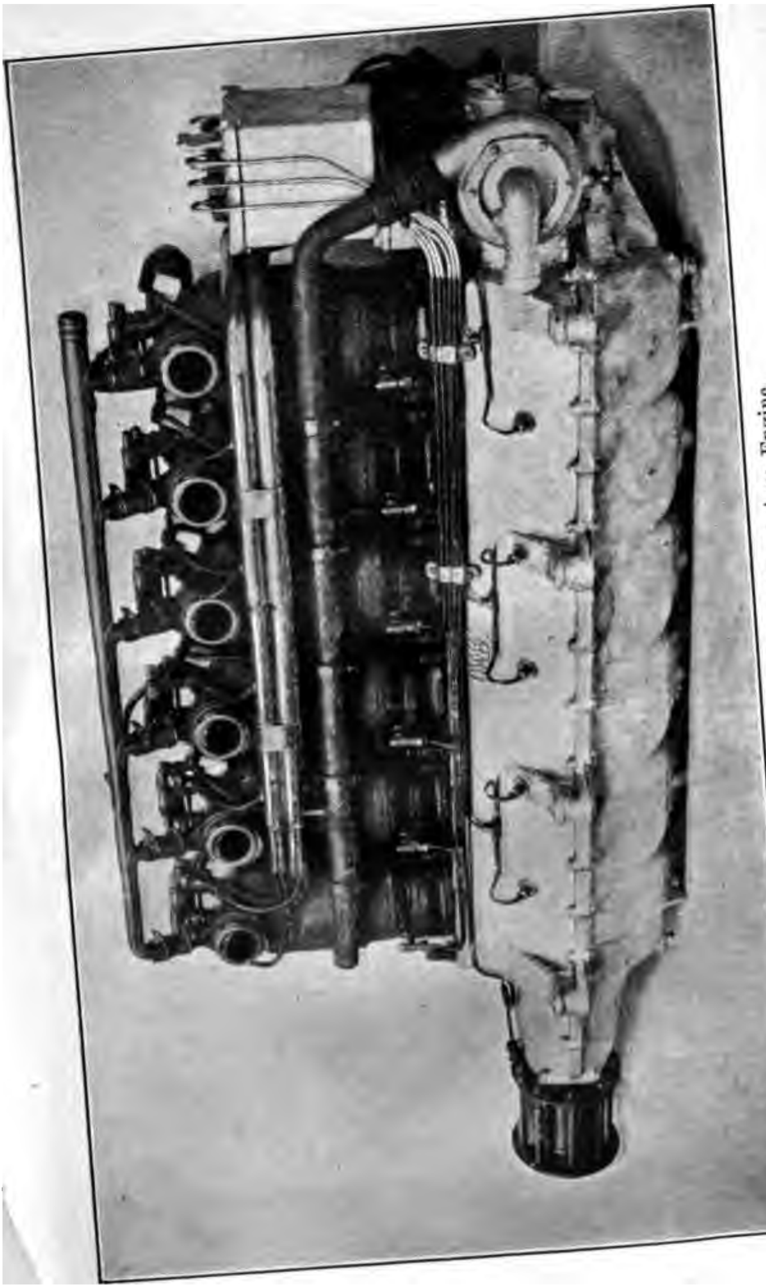


Fig. 49.—The 90 H.P. Beardmore Aero Engine.

To face p. 70. KEAN, AERONAUTICAL ENGINES.]

pistons are of pressed steel with dished heads. The crankcase is of aluminium and the crankshaft is supported therein by seven bearings. At the front end of the engine the propeller boss may be seen, and just behind it a double thrust ball race is fitted; at the rear end the magneto and the Bosch lubricator are fitted. The magneto is arranged for dual ignition so that the engine may be started from the pilot's seat. The lubricator has valveless piston pumps and feeds all bearings under

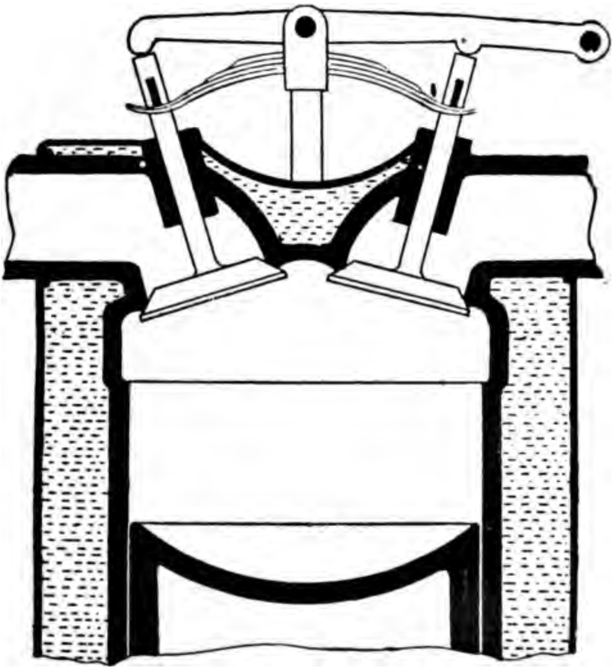


FIG. 51.—Diagrammatic Section of the Cylinder Head on the Beardmore Aero Engine.

pressure thus securing perfect lubrication. The centrifugal water pump may also be clearly seen; it takes the water from a honeycomb radiator and pumps it through the cylinder jackets and so back to the radiator. The arrangement of the valve gear is unique, as a single laminated plate spring controls both inlet and exhaust valves, although it necessitates the use of a special type of cam to give a positive return motion to the tappet rod. The inlet valve is in detachable cage. Two Beardmore carburettors are fitted; these are of simple design with cylindrical throttle and arranged so that the float chamber surrounds the choke tube. The beautiful photographs of the 120 horse-power engine were specially prepared for the Author by the kindness of the Beardmore firm. For some time now these engines have been noted for their low fuel and oil consumption and their low weight per horse-power, but it is not possible to publish any of the latest figures at present; the figures given in Table IV may serve as a guide to indicate how rapid the progress has been with all types of engines during the last twelve or eighteen months, but these do not refer to any existing engines; they merely represent a fairly accurate comparison of the several types of engines set out in the table. The following figures are taken from a catalogue issued by this firm some months ago, before the present extraordinary developments in design and construction took place.

PLATE 7.

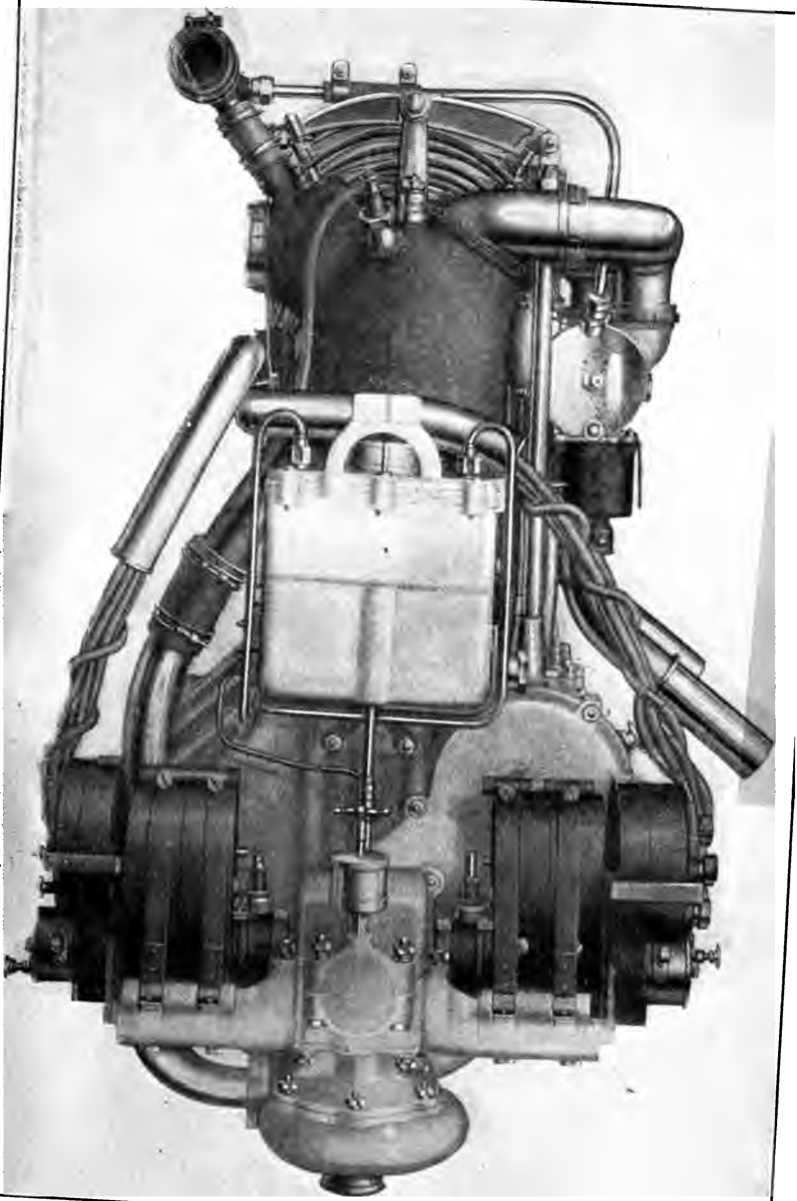


Fig. 52.—End View of the 120 H.P. Beardmore Aero Engine, showing Magnetos and Oil and Water Pump Arrangements.

To face p. 72. Kean, Aeronautical Engines |

PLATE 8.

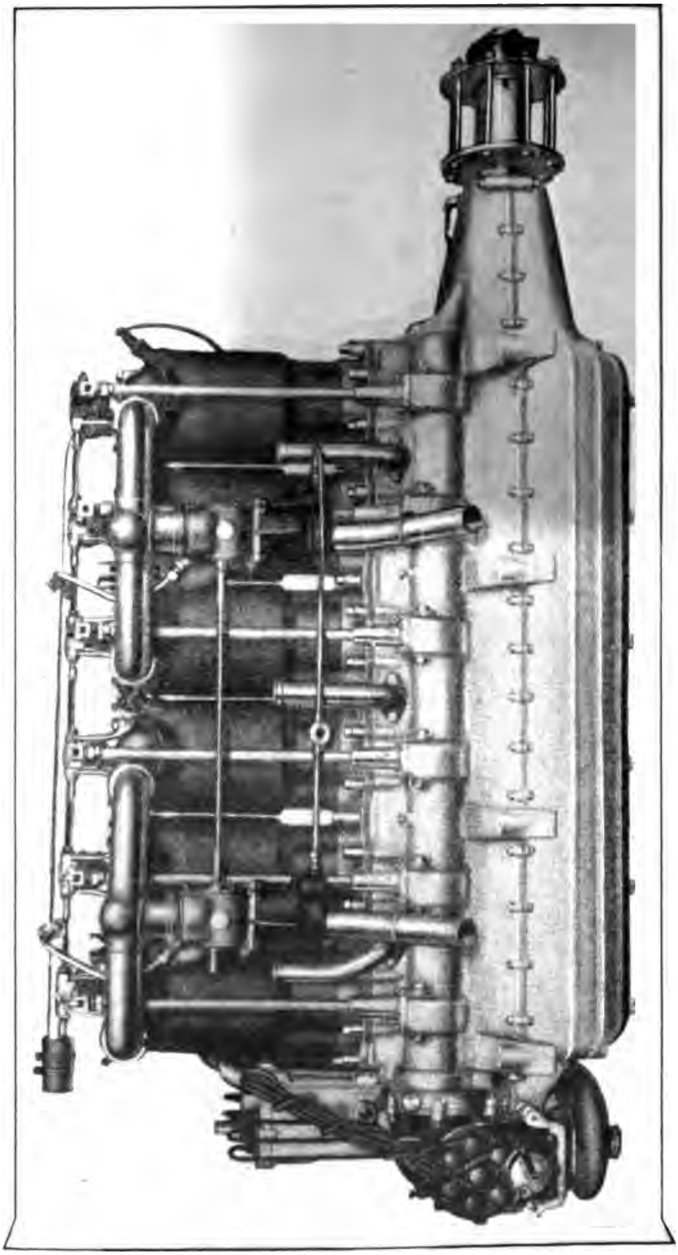


FIG. 53.—Induction side of the 120 H.P. Beardmore Aero Engine, showing the arrangement of Carburettors and Valve Gear.

The 90 *Horse-power Engine.* Bore 120 m.m.; stroke 140 m.m.; speed at normal revolutions 1,300 per minute; petrol consumption 0.6 pints per b.h.p. hour; oil consumption 0.025 pints per horse-power per hour; weight per brake horse-power 4.5 lb., including radiator and all accessories and piping.

The 120 *Horse-power Engine.* Bore 130 m.m.; stroke 175 m.m.; speed at normal revolutions 1,200 per minute; petrol consumption 0.6 pint per b.h.p. hour; oil consumption 0.025 pint per horse-power per hour; weight per brake horse-power, including radiator and all accessories and piping, 4.5 lb.

II. The Wolseley Engine

The Wolseley Tool & Motor Car Co. have specialized with Vee engines, both air and water cooled. In Figs. 55 and 56 we show two views of the 90 horse-power semi-air-cooled eight-cylinder engine, clearly showing every detail of the valve gear and giving an excellent idea of the general arrangement of the piping and accessories. In Figs. 57 and 58 we show two views of the 130 horse-power wholly water-cooled eight-cylinder engine. The photographs from which these blocks were prepared were very kindly presented to me by the Wolseley Co. It will be seen that the valves are in the head of the cylinder, but are not inclined in this case. To ensure ample space for large diameter valves we find they are offset from the cylinder centre line, and this can be clearly seen in Fig. 58. The crankcase is of aluminium, having the cylinders bolted to it at an angle of 90°, the crankshaft being supported by three bearings and having two connecting rods operating on each crankpin. Both types of engine have their cylinders constructed from high carbon steel and turned out of the solid ingot. The water jackets of the 130 horse-power engine are formed of sheet copper. Steel pistons are also used. The camshaft passes between the two groups of cylinders and operates both sets of valves; at the end of the camshaft we find strong reduction gearing is fitted for the propeller drive, the propeller running at half the crankshaft speed. The valves are fitted in detachable cages and are actuated by long tappet rods connected to overhead rocking levers. The Claudel-Hobson carburettor is used and Bosch dual high tension magneto ignition. In Fig. 57 the carburettor and magneto are fitted in the Vee, but they may also be fitted at the end of the engine if desired. The form of the cylinder barrel is shown diagrammatically by the sectioned drawing of Fig. 59 which represents the air-cooled engine arrangement. Lubrication is by means of two gear pumps, one being arranged for suction from the crankcase sump and the other for delivery to the main bearings and crankpins under pressure. The remainder of the lubrication is effected quite well by "splash." The Wolseley Co. have ex-

PLATE 9.

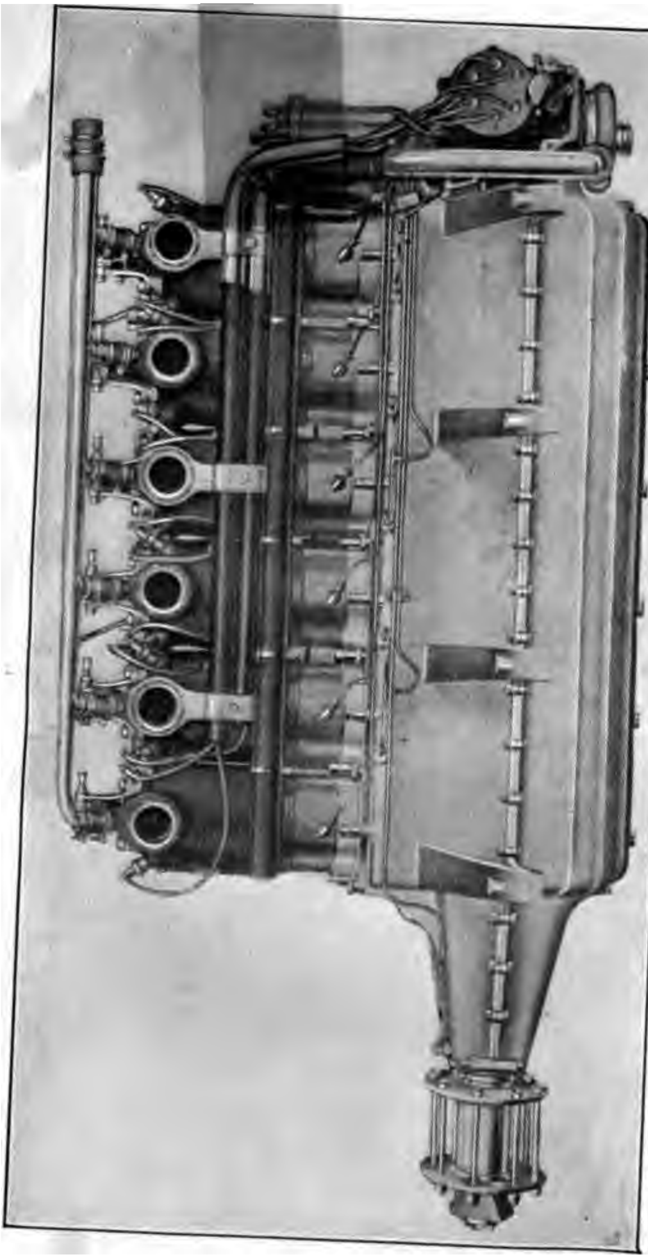


FIG. 54.—Exhaust side of the 120 H.P. Beardmore Aero Engine, showing the Water Circulation System.

To face p. 74, KEAN, AERONAUTICAL ENGINES.]

pressed regret at not being able, under present circumstances, to supply me with particulars of their most up-to-date engines, but the engines I have described belong to the period immediately preceding the outbreak of war. The following figures were published by this firm in a catalogue issued some months ago:—

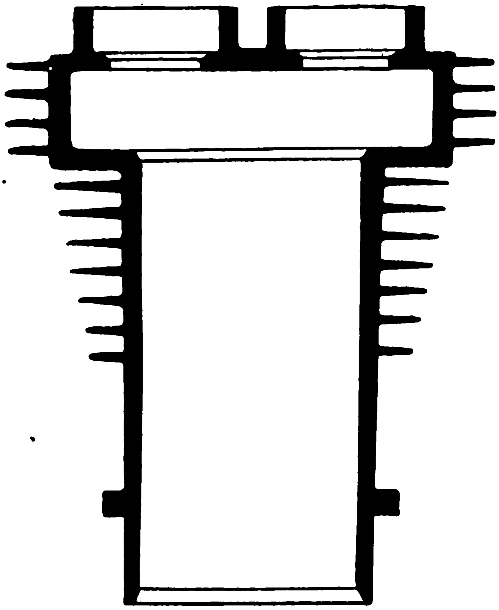


FIG. 59.—Diagrammatic Section of Air-cooled Cylinder for Wolseley Engines.

The 90 *Horse-power Semi-air-cooled Engine.* This engine has the exhaust valve fitted in a water-jacketed detachable cage, but the inlet valve and the cylinder head are wholly air-cooled. A small gear pump is used to circulate the water through the valve boxes and a honeycomb radiator is fitted to cool the water. The speed of the engine is 1,800 revolutions per minute when developing 90 b.h.p. with eight cylinders, each having a bore of 4 in. and the stroke being 5½ in. The weight of the engine only is 400 lb. when empty.

The 130 *Horse-power Engine.* This engine is wholly water-cooled, the pump being clearly visible in Fig. 58. At 1,200 revolutions per minute the engine develops 130 brake horse-power with eight cylinders, each having a bore of 5 in. and the stroke being 7 in. Being a relatively slow speed engine and water-cooled the weight is fairly high, being estimated at 700 lb. There is no doubt whatever that this figure will have been cut down very considerably at the present time.

III. THE SALMSON ENGINE (CANTON-UNNÉ SYSTEM)

This is a radial engine having fixed water-cooled cylinders and rotating crankshaft, being generally mounted right in front of the aeroplane, as shown in Fig. 60. The sole selling agents for the British Empire are the Dudbridge Iron Works, Ltd., of Stroud, Gloucester, to whom I am indebted for the unique photographs accompanying this description. The description of the Salmson engine given below is based on information supplied by this Firm and on personal observations of the writer. Through the courtesy of

PLATE 11.

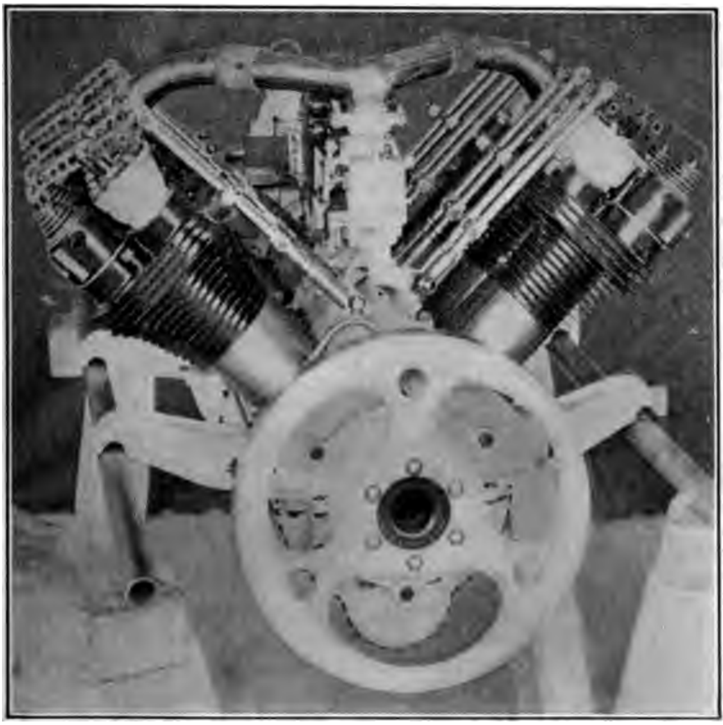


Fig. 56.—Wolseley 90 H.P. Semi-air-cooled Eight-cylinder Vee Aero Engine, showing arrangement of Tappet Rods, Valve Boxes, and Carburettor.

To face p. 76, KEAN, AERONAUTICAL ENGINES.]

PLATE 12.

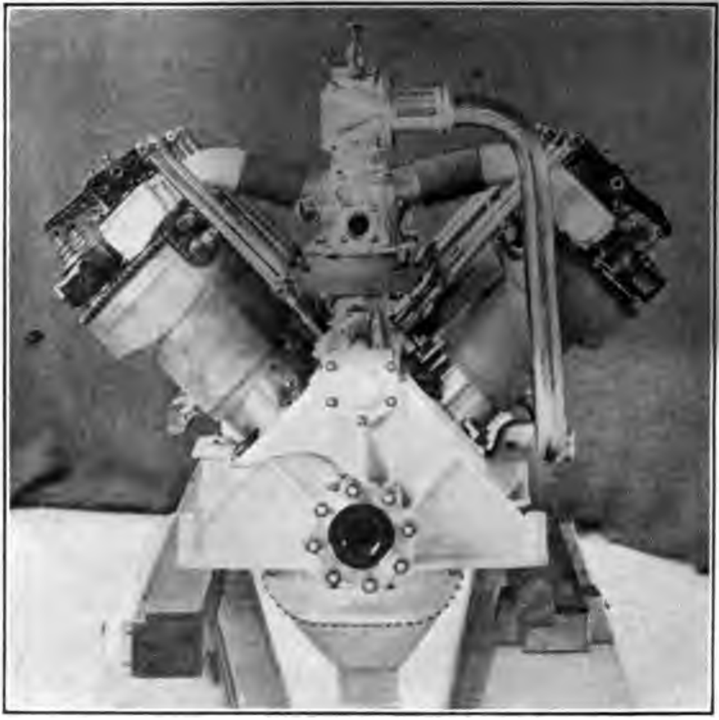


FIG. 57.—End View of 130 H.P. Wolseley Eight-cylinder Water-cooled Vee Aero Engine, showing arrangement of Carburettor and Induction Pipes.

Messrs. Willans & Robinson, of Rugby, I was able to see these engines in course of design and construction, and on the test bed; every facility was granted me to get a thorough grasp of the many problems which had been faced and surmounted. Briefly we may say that three types of engine have been constructed and others are in course of preparation. There are the M7, the M9, and the 2M7 types. The M7 has seven cylinders; the M9 has 9 cylinders; and the 2M7 has fourteen cylinders, being in reality a double M7 engine. The horsepower and other dimensions are given later. The cylinders of the 2M7 are staggered so that the crankshaft receives seven firing impulses per revolution.

The cylinders are of forged steel machined inside and out. The valves are mounted in the head of the cylinder, their seatings being integral with the main forging. The head of the cylinder has a flat surface formed above it to make the water jacket joint, and the intervening space is very carefully gouged out to reduce the weight and allow the water to circulate freely all round the valve pockets. The water jacket is formed of spun sheet copper brazed to the cylinder at the lower end and clamped at the upper end by the valve cages. It will be noticed that the jacket has a "bellows" formed in it to allow for expansion. The complete cylinder with water jacket is wonderfully light and its thickness varies from 2 m.m. at the bottom up to 4 m.m. at the top. The method of securing the cylinders is also very ingenious; the crankcase is bored out and screwed, then a screwed split ring is inserted into a groove formed on the outside of the cylinder. The cylinder is next screwed into the crankcase and locked in position by a special clamping band, drawn together at the ends by a bolt. The standard pistons are of cast iron machined inside and out as far as possible and having domed heads; it may be noted here that other materials are also being used for the pistons in the later engines. The complete set of pistons and connecting rods when assembled is very carefully weighed and must conform to such strict limits that a deviation of 1 gramme for a piston and rod, or 0.5 gramme for a piston only, is the maximum permissible. The connecting rods have both ends alike, are of high grade steel, and bushed with phosphor bronze. The general arrangement of the mechanism will be understood by reference to Fig. 61, from which it will be seen that the crankpin carries a steel collar having as many pins fitted through it as there are cylinders to the engine. As this arrangement would give no positive drive, a very ingenious arrangement of gear wheels is adopted. The collar has a gear wheel C rigidly fixed to it which gears with the planet pinion B. The pinion B is very wide and meshes with a fixed wheel A attached to the crankcase. The wheels A and C have the same number of teeth, so that as the crank rotates in the direction of the arrow the

PLATE 13.

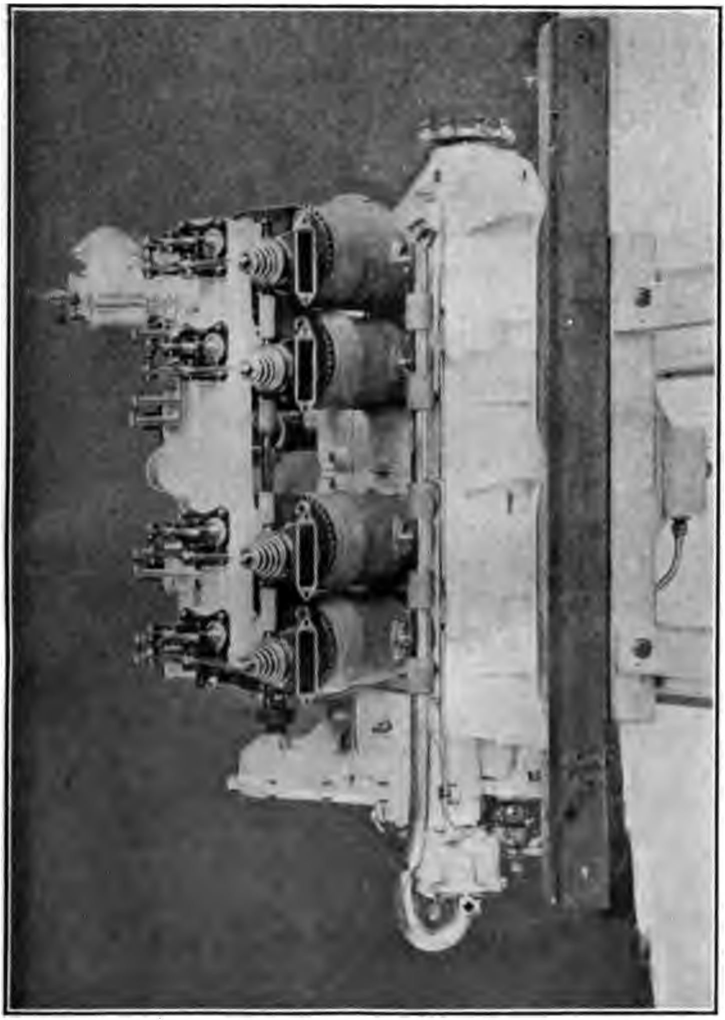


Fig. 58.—Wolseley 130 H.P. Water-cooled Eight-cylinder Vee Aero Engine, showing relative position of Valve Boxes on Cylinder Heads.

To face p. 78. Kean, Aeronautical Engines.]

PLATE 14.

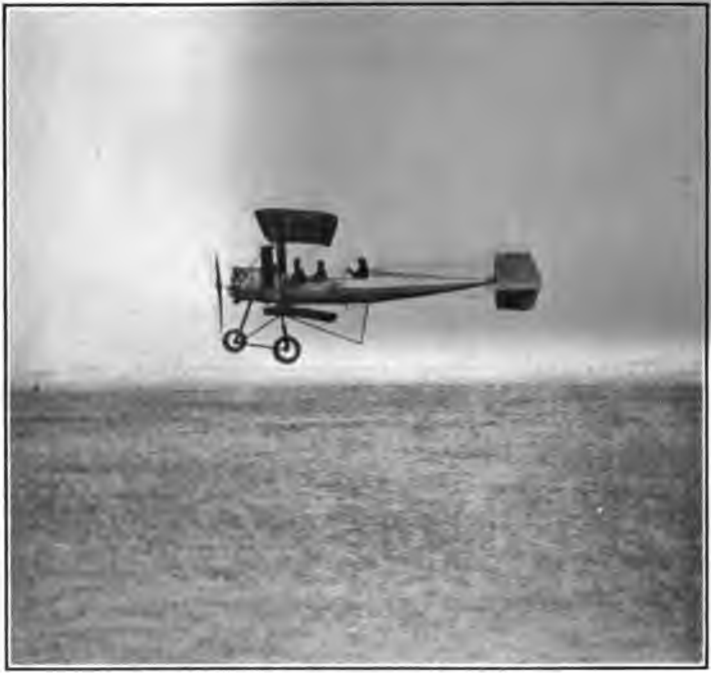


FIG. 60.—Aeroplane fitted with the Salmson Engine.

collar is driven back at the same speed, thus each pin in the collar always faces its own cylinder

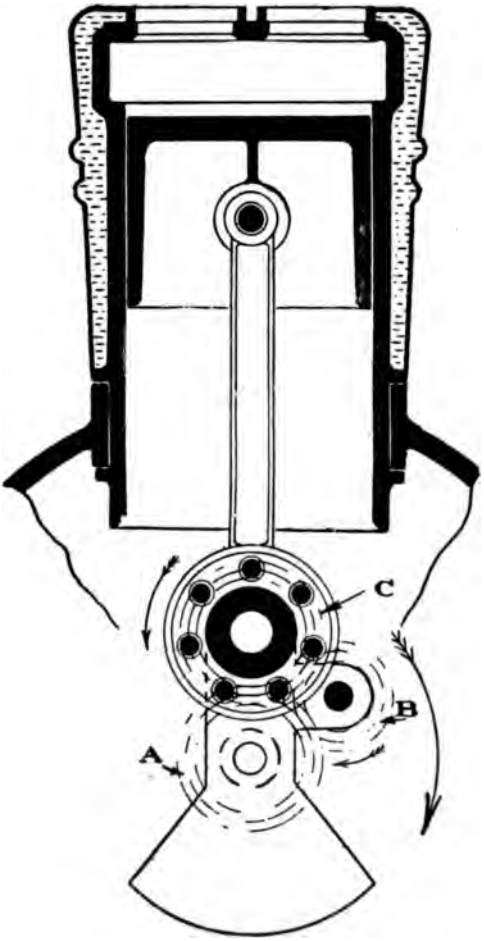


FIG. 61.—Diagrammatic Section of the Cylinder of a Salmson Aero Engine (Canton-Unné System).

and each connecting rod end traces out a crankpin path of its own immediately in front of its

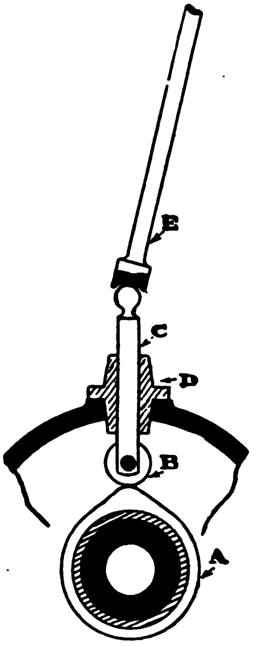
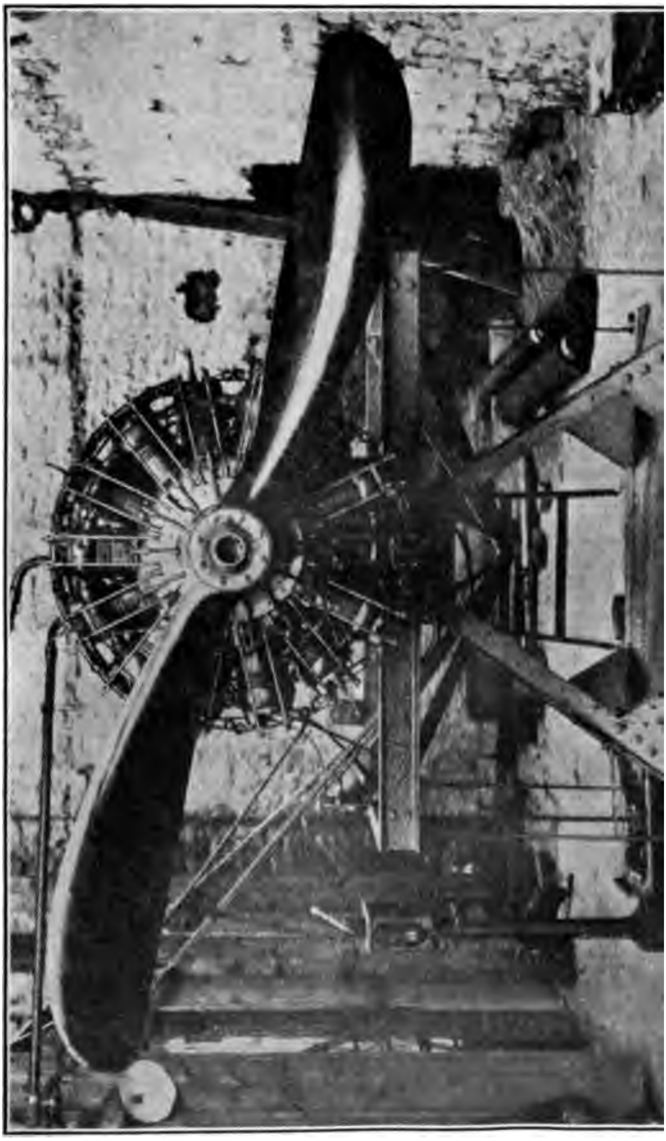


FIG. 62.—Arrangement of Valve Gear for a Radial or Rotary Aero Engine.

own cylinder not coincident with the path of the main crankpin. The crank web is splayed out to form a bearing for wheel B, and is also very carefully balanced by balancing masses. The arrangement of the valve gear on the M9 engine will be understood from Fig. 62, which shows at A one of the nine cams driven by gearing from the crankshaft through an intermediate wheel supported on the crankcase. At B the tappet roller of large diameter is seen fixed to the ball-headed tappet C which passes through the bronze guide D. A ball socket is formed at the lower end of the tappet rod or push rod E, the upper end being forked. In the 2M7 engines a special form of guide is used for the tappet, as the rods of the rear set of cylinders are more inclined than those of the front set, the valve gear being always in front of the engine. The rocking lever on the head of the cylinder has a ball joint for operating the valve. In the M7 engine there are only two cams each having three projections; in the 2M7 engine there are four cams

PLATE 15.



To face p. 80. KEAN, AERONAUTICAL ENGINES.]

PLATE 16.

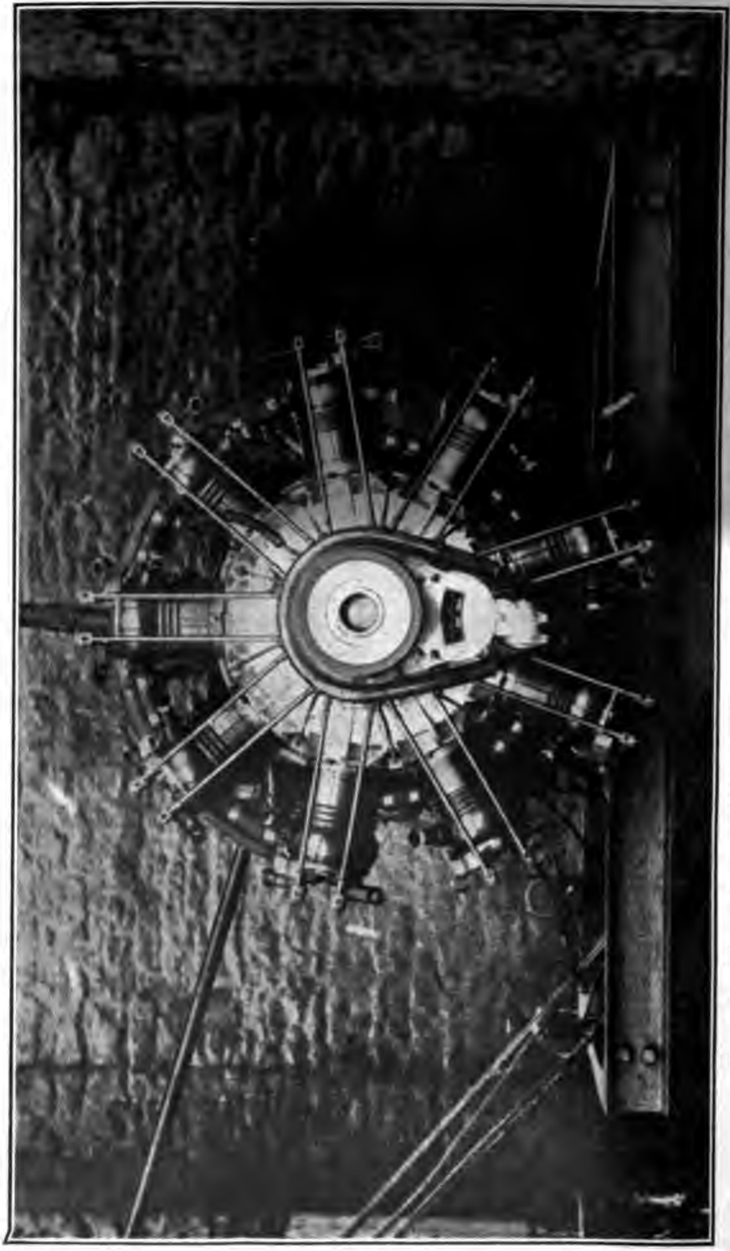


FIG. 66.—Nine-cylinder 130 H.P. Salmson Radial, Water-cooled Aero Engine on test.

with three projections each; in the M9 engine there are nine cams each having a single projection. The valves are of tungsten steel and of the form shown in Fig. 63. Another form of valve frequently used in other makes of engine is the stream-line form of Fig. 64. The valve springs are of grasshopper pattern and can be clearly seen in the photographs, of which Fig. 65 is the 2M7 engine, and Fig. 68 the M9 engine shown mounted on the test bed. Rotation is clockwise, viewed from the propeller end. The Zenith carburettor is used and provided with a special exhaust gas heater round the mixing chamber; in addition to this the petrol vapour is taken to the cylinders through an annular duct cast round the back of the aluminium crankcase. The oil pumps, water pump, and magneto are at the rear of the engine. Generally the Bosch magneto is used. The firing order of the M7 engine would be 1, 6, 4, 2, 7, 5, 3, and of the 2M7 engine it would be 1, 1*a*, 6, 6*a*, etc. Lubrication is by two plunger pumps, one drawing the oil from the crankcase and passing it to the tank, while the other feeds the oil to the bearings and along the centre of the hollow crankshaft to the crankpin. The connecting rods and pistons are lubricated by splash. The following figures have

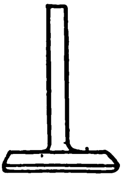


FIG. 63.—Flat Disc, Mushroom type Valve for Aero Engine.

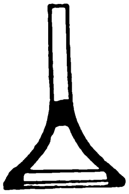


FIG. 64.—Stream-line Section, Mushroom Valve for Aero Engine.

been published by the Dudbridge Iron Works, Ltd., in one of their catalogues, but it should be carefully noted that these figures do not refer to the latest and most up-to-date engines:—

Type.	B.H.P.	Cylinders.	Bore.	Stroke	R.P.M.
M7	90–100	7	120 m/m	140 m/m	1250
M9	130–140	9	120 m/m	140 m/m	1250
2M7	200–220	14	120 m/m	140 m/m	1250

The consumption of petrol is stated to be 0.6 pint per b.h.p. per hour, and the consumption of lubricating oil is given as 0.025 lb. per b.h.p. hour.

IV. THE ANZANI ENGINE

This is a radial air-cooled engine with fixed cylinders and rotating crankshaft. The British Anzani Engine Co. have kindly allowed me to reproduce some of the excellent photographs from their catalogue; I am also indebted to the Company, for allowing me to visit the works and examine all the parts of the ten-cylinder 100 horse-power engine. The company also build many other types the most important of which is probably the 200 horse-power twenty-cylinder engine. Many records have been made and many prizes won by aeroplanes fitted with the Anzani

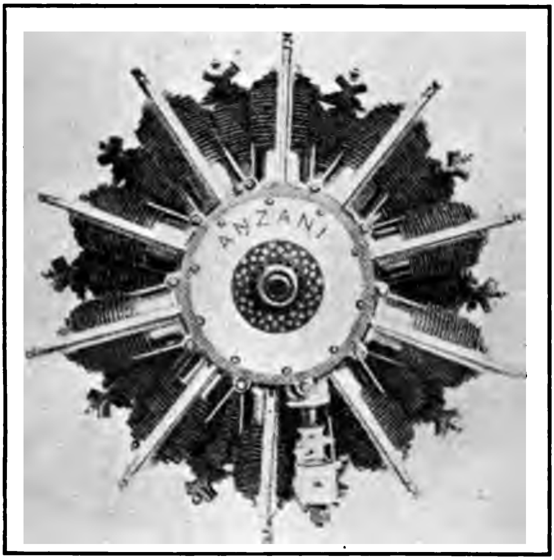


FIG. 67.—The 200 H.P. Twenty-cylinder Anzani Radial Air-cooled Engine, showing position of Carburettor.

air-cooled engines. The ten-cylinder engine is arranged as two groups of five cylinders set star fashion. The twenty-cylinder, illustrated in Figs. 67, 68, 69 and 70, is arranged in four groups of five cylinders each. The parts of the ten-cylinder engine are shown in Fig. 71. From an examination of the photographs it will be observed that the crankcase, which is of aluminium, is split into two portions which are bolted together by longitudinal bolts. The cylinders, which are of cast iron, are then inserted and held in position firmly by long stay bolts pivoted at one end on the crankcase bolts and passing through lugs formed on the outside of the *head* of the cylinder. This arrangement is excellent as it relieves the cylinder barrel of tensible stress. Cast-iron pistons are used and flat disc valves (see Fig. 63). The inlet valves are automatic, but the exhaust valves are mechanically operated in a manner very similar to that shown in Fig. 62. There are, however, only two cams in this engine each having two projections and being driven at one-fourth of the engine speed; these operate all the ten exhaust valves. The peculiar arrangement of the crankpin should be noted, as this is specially designed to bring the axes of the two sets of cylinders into close alignment and thus reduce the unbalanced couple to a minimum. Probably the most interesting device in the whole engine is the crankpin bearing for the connecting rods. Each connecting rod is of special steel alloy bushed at the pis-

Lubrication is by a plunger ty
ranged as a poppet valve. High
ignition is used and the Zenith c
ted. It will be noticed that the
placed low to allow of gravity fee
thoroughly warmed by passing it
nular chamber surrounding the c
following figures are published fo
of engine:—

The twenty-cylinder engine has
of 140 m.m. and cylinder bore of 105
ing 200 horse-power at 1,250 revolu
ute. The weight, complete, is 3.4
power. Petrol consumption is (
horse-power per hour, and oil con
pints per horse-power per hour.

The ten-cylinder engine has a pi
145 m.m. and cylinder bore of 150 m
100 horse-power

PLATE 19.

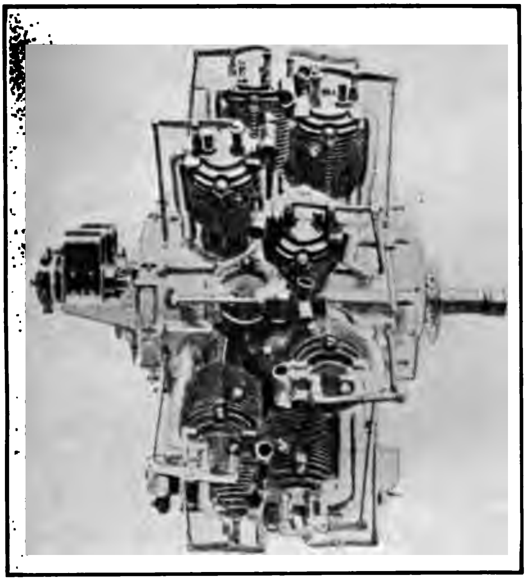
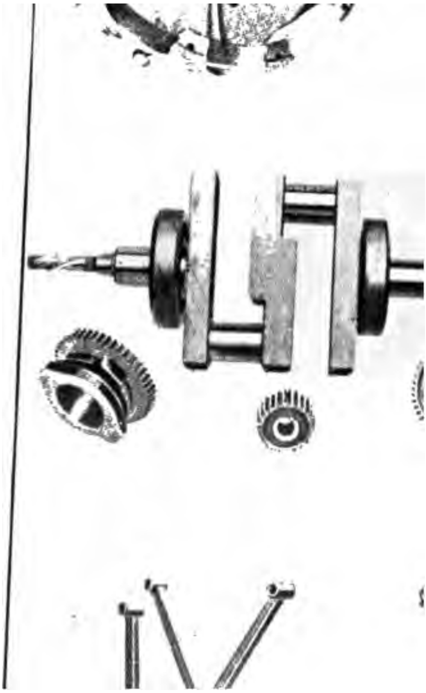


Fig. 70.—Side view of the 200 H.P. Twenty-cylinder Anzani Radial Air-cooled Aero Engine, showing position of Magneto and arrangement of Valve Gear.

To face p. 84, Kean, Aeronautical Engines.]



V. THE GNOME ENGINE

This is an air-cooled engine having rotating cylinders and fixed crankshaft. I am greatly indebted to Messrs. Peter Hooker of Walthamstow for the unique photographs accompanying this description which were all specially taken for me, and also for two complete sets of working drawings of the Gnome and Le Rhone engines. Unfortunately at the present time it would be indiscreet to reproduce the working drawings, but at some future date I hope to be able to do so; the photographs and the diagram I have prepared in Fig. 72 should clearly explain the action of the engine. Perhaps the best known type of Gnome engine is the 80 horse-power seven-cylinder bi-valve type having an automatic balanced inlet valve in the head of the piston and a mechanically operated exhaust valve in the head of the cylinder. The Le Rhone engine referred to above has nine cylinders each 105 m.m. bore, and the equivalent piston stroke is 140 m.m., which enables it to develop 80 horse-power at 1,200 revolutions per minute. It has two mechanically operated valves in the head of the cylinder, and the petrol vapour and air passes through the crankchamber and up to each inlet valve by a separate short induction pipe. There is a master connecting rod to the big end of which two plates are attached carrying concentric grooves for the remaining big ends. A single rocking lever attached to a fulcrum fixed in the centre of the cylinder head serves to operate both valves, i.e. inlet and exhaust. The most modern type of Gnome engine is the mono-valve engine giving 100 horse-power at 1,200 revolutions per

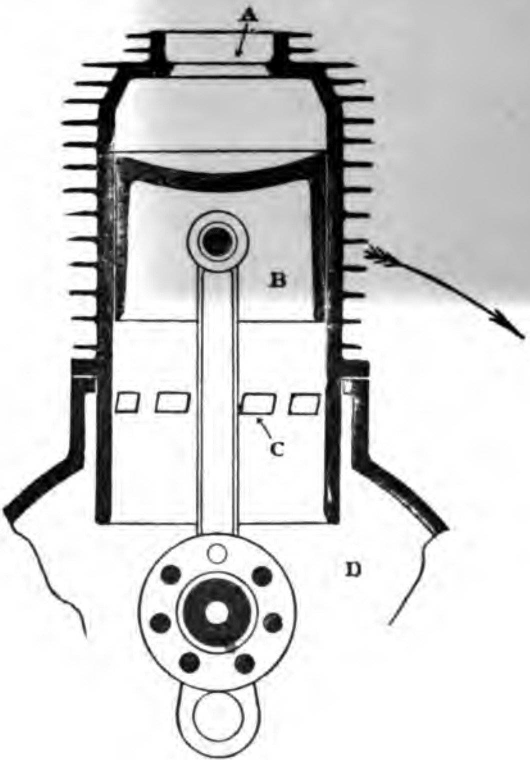


FIG. 72.—Diagrammatic Sketch to illustrate the working of the Gnome Aero Engine.

minute, having nine cylinders each 100 m.m. bore and with an equivalent piston stroke of 150 m.m. It will be seen from Fig. 73 that the crankshaft is hollow and it is also stationary, the cylinders being

PLATE 21.

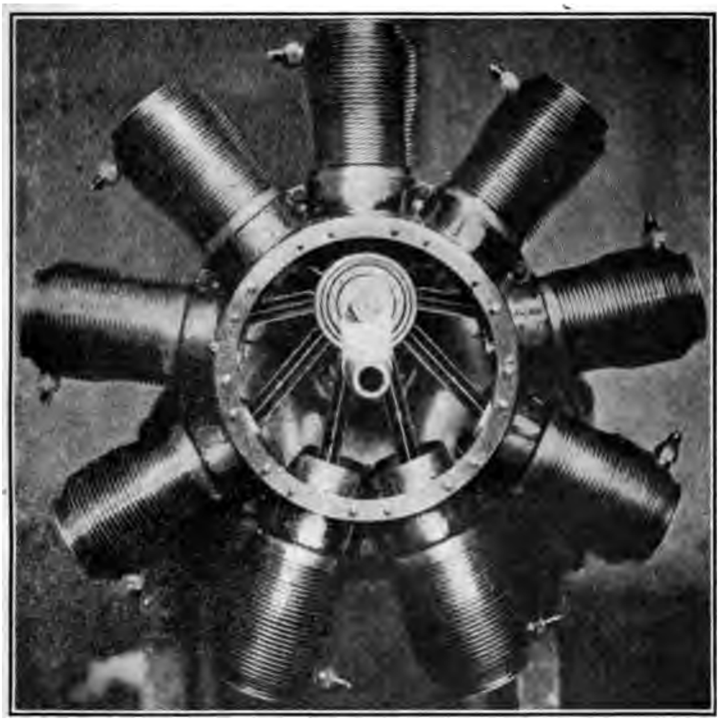


FIG. 73.—100 H.P. Nine-cylinder Gnome Engine constructed by Messrs. Peter Hooker, Ltd., of Walthamstow, London.

To face p. 86, KEAN, AERONAUTICAL ENGINES.]

grouped symmetrically round its centre and the pistons being grouped symmetrically about the crankpin. Considering any one of the cylinders, except that immediately above and in line with the stationary crank arm, it will be readily seen that the force of the explosion on the head of the piston causes a great thrust along the connecting rod which can be resolved into two components; one acting along the axis of the cylinder does no useful work, but the other acting at *right angles to the cylinder axis* exerts a powerful torque about the crankshaft centre and thus rotates the whole crankcase and cylinders in the manner of a flywheel. The main engine fixing plate is situated immediately behind the crankcase in Fig. 73, and there would be a second fixing plate at the end of the long crankshaft, while a third supporting plate would often be fixed in front of the engine to take the weight of the overhanging portion, although this is not done in the case of the Hooker engines here illustrated. We notice the ingenious arrangement adopted for carrying out a brake test, the torque being measured direct at the cradle by means of the weights seen on the left of Figs. 74 and 75. The fan brake is used here to take up the power instead of the propeller, so that there is no end thrust on the testing chassis. The exhaust valves are placed in the heads of the cylinders and operated by tappets, push rods, and rocking levers in the usual manner, the cams being driven by gearing from the rotating crankcase. The petrol and lubricating oil are pumped into the crankcase through nipples which are screwed into the hollow stationary crankshaft. The throttle control valve is fixed at the far end of the hollow crankshaft and only admits sufficient air to the crankchamber to vaporize the liquid petrol therein, but not enough to form an *explosive* mixture. An explosive mixture is one containing about 98 per cent. of pure air, so that there is little danger of the crankcase mixture igniting. The method of forming the explosive mixture is as follows:—On the suction stroke of the piston B (i.e. the operation which corresponds to a stroke, but is in reality only a relative displacement of piston and cylinder without translatory motion of the piston) the exhaust valve which is fitted at A (see Fig. 72) is kept open during half the stroke so that pure air is drawn into the cylinder (there being no exhaust box). After the exhaust valve is closed a suction is created in the cylinder during the second portion of the stroke, so that when the piston overruns the ports C it draws the rich mixture from the crankcase D into the cylinder. During the compression stroke dilution and remixing occur in the cylinder, thus bringing the contents to the correct proportions for exploding. The exhaust valve opens very early in the firing stroke, so that there is not enough pressure in the cylinder to cause the products to blow into the crankchamber when the ports are uncovered by the piston at the end of the firing stroke, and in any case the gas is

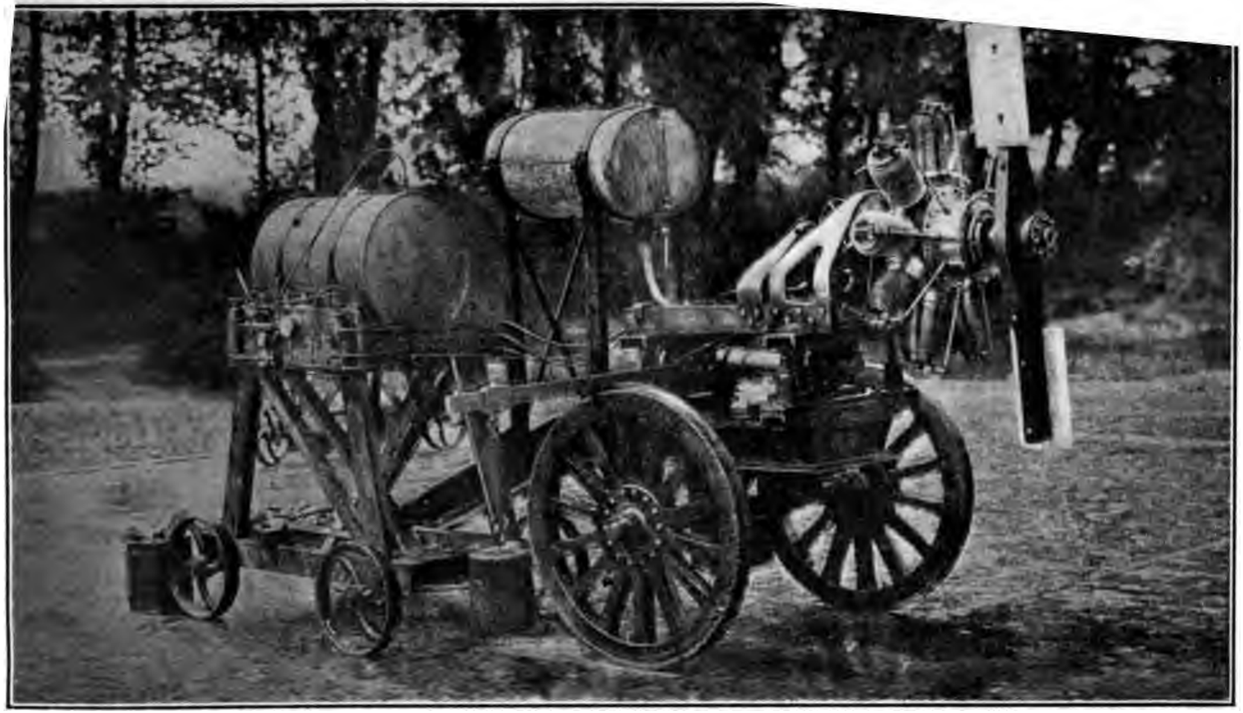


Fig. 74.—Nine-cylinder Gnome Engine (constructed by Messrs. Peter Hooker, Ltd.), with Fuel and Oil Tanks complete, ready for test.

PLATE 23.

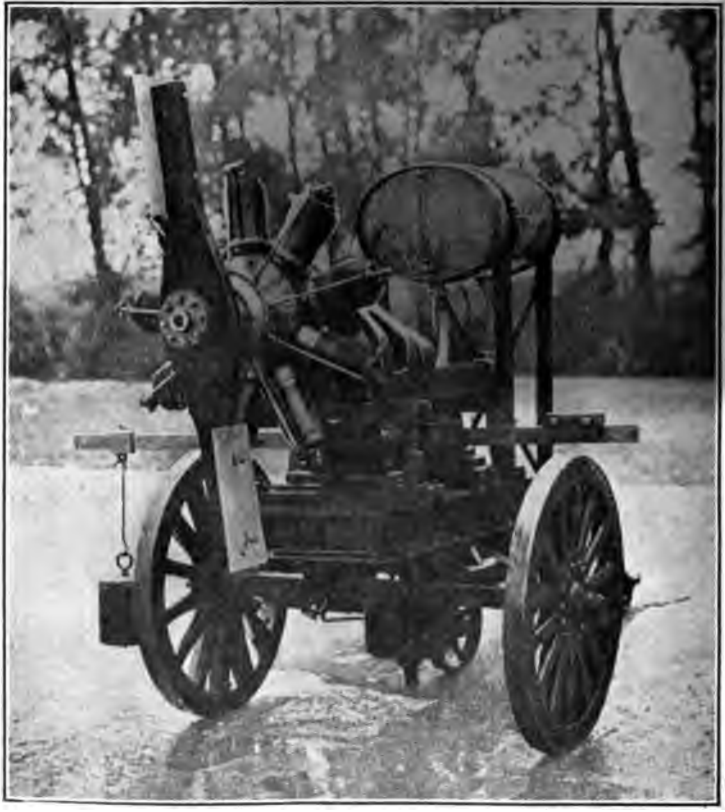


Fig. 75.—Nine-cylinder Gnome Engine (constructed by Messrs. Peter Hooker, Ltd.), mounted on the testing chassis.

too rich to ignite readily. The two most important features of the Gnome engine are the master connecting rod, shown in Fig. 76, and the *obturateur* rings used on the pistons. The master rod is mounted on the crankpin and fitted with ball bearings; each of the remaining connecting rods works on a gudgeon pin fitted between the flanges of the master rod. Oil pipes will be observed which lead the oil up to the gudgeon pin and so through the hollow pin on to the cylinder walls. In spite of the fact that the obturateur rings, which are of bronze and of a special section, must cause excessive friction loss, I am told they are absolutely essential for successful continuous operation—possibly due to the distortion of the cylinder under heat. These rings are placed very near to the top of the piston and are in addition to the packing rings. It will be readily understood that the temperature of the cylinder bore cannot be uniform the whole way round as the front and rear faces of the engine will be better cooled than the portions of the cylinders adjacent to each other and situated in the Vee's. The cylinders are of steel and likewise the crankcase; they are held in place (by two collars) between the two halves of crankcase. The exhaust valve is cooled considerably by the introduction of the clean air on the suction stroke; also the valve gear is lubricated by allowing oil to flow up the hollow tappet rods. The oil pump is shown in Fig. 77 and the oil-heating device in Fig. 78. The magneto is attached to the main engine fixing plate and the high tension electrode delivers the current to a rotary distributor attached to the back end of the crankcase. The ignition wires leading from the distributor to the plugs are bare, as heavy insulation would probably be disintegrated under centrifugal force. The crankcase is mounted on ball bearings. According to some figures which were published in *Engineering* for March 20, 1914, the consumption of petrol by a 100 horse-power Gnome monosoupape engine was 0.64 lb. per horse-power per hour, and the consumption of lubricating oil was 0.09 lb., per horse-power per hour; these figures do not relate to the Hooker engines described above, however.

VI. The Curtiss Engine

The Curtiss Aeroplane Co. of Buffalo, New York, U. S. A., have manufactured large numbers of aeroplane engines. I am indebted to the London office of the Firm for the particulars on which the following description is based and the photographs of these engines. There are two principal sizes, the OX and the VX, both being V engines with water-cooled cylinders. The VX engine has forged steel cylinders with sheet metal water jacket welded on the outside. The cylinders are bolted to the crankcase by ordinary studs, but are staggered. The OX engine has cast-iron cylinders with sheet metal water jacket welded on the

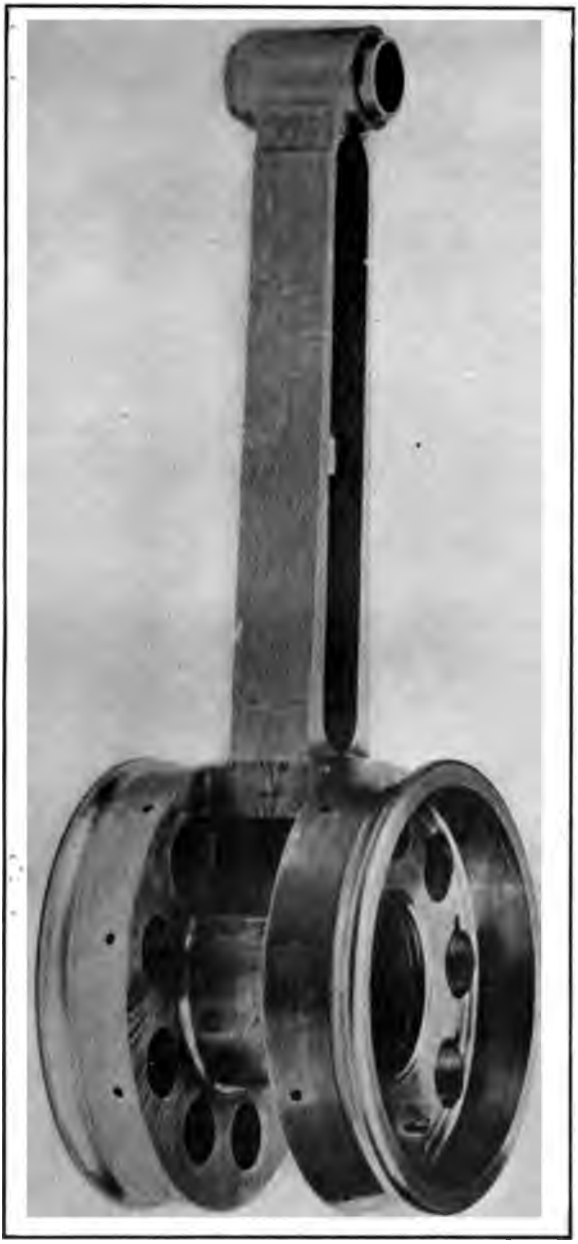


FIG. 76.—Master Connecting Rod of the (Hooker) Gnome Engine.

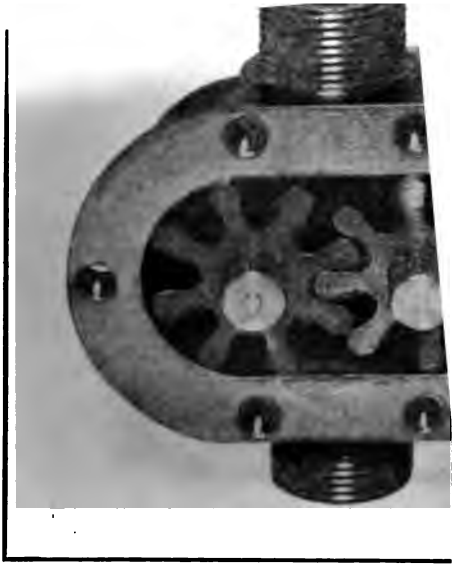


FIG. 77.—Oil Pump fitted on a (Hooker

outside. The cylinders are bolted to the crankcase by four ordinary studs and four long studs extending to the head. The valve chambers and valve stem guides are cast in one piece with the cylinder barrel. In both engines the valves are overhead but operated by long push rods from an ordinary camshaft. The inlets are of nickel steel and the exhausts of tungsten steel. The valve springs are both of helical pattern on the OX engine, but on the VX engine the exhaust has a cantilever spring. The pistons are of special aluminium alloy with ordinary cast-iron rings and chrome-vanadium steel wrist pins. The connecting rods are of H section, machined all over and heat treated. The crankshafts are of chrome-nickel steel. The timing wheels are spur pattern, the pinion being steel and the wheel manganese bronze. The exhaust pipes are of steel. Ignition is by high tension single-spark magneto. Two separate magnetos are fitted on the VX motors and a single magneto on the OX motor. Two Zenith carburettors are fitted, one for each bank of four cylinders. Lubrication is by rotary gear pumps drawing oil from the reservoir and pumping it through the hollow camshaft to the crankshaft and main bearings, and thence through the connecting rod oil pipes to the piston pins and cylinder walls. The oil pressure at normal engine speed is about 50 lb. per square inch. The main bearings are of bronze, lined with white metal. The camshaft bearings are of aluminium alloy.

Photographs of the engines are shown in Figs. 79 and 80. Particulars of the output, etc., are given in Table XI.

TABLE XI

Type of Engine.	OX	VX
Number of cylinders	8	8
Bore of cylinder	4″	5″
Stroke of piston	5″	7″
Normal speed in revs. per min.	1,400	1,400
Horse-power at normal speed .	100	200
Weight with all accessories, but without oil and water .	400 lb.	700 lb.
Petrol consumption, per hour	8.3 gallons	15 gallons
Oil consumption per hour . .	0.4 gallon	0.75 gallon

VII. The Mercédès Engine

This is a vertical-in-line engine with water-cooled cylinders and overhead camshaft driven by gearing. The Mercédès Motor Co. of Long Acre, London, W. C., have kindly supplied the following particulars and photographs of the 100 horse-power engine. It has six cylinders, cast in pairs. The bore is 120 m.m. and the stroke 140 m.m. The normal speed is 1,300 revolutions per minute. Both inlet and exhaust valves are mechanically operated. Ignition is by two high tension magnetos, and a special carburettor is fitted. The weight of the complete engine with all piping and accessories is 444 lb. The petrol consumption at full power is 7½ gallons per hour, and the oil con-

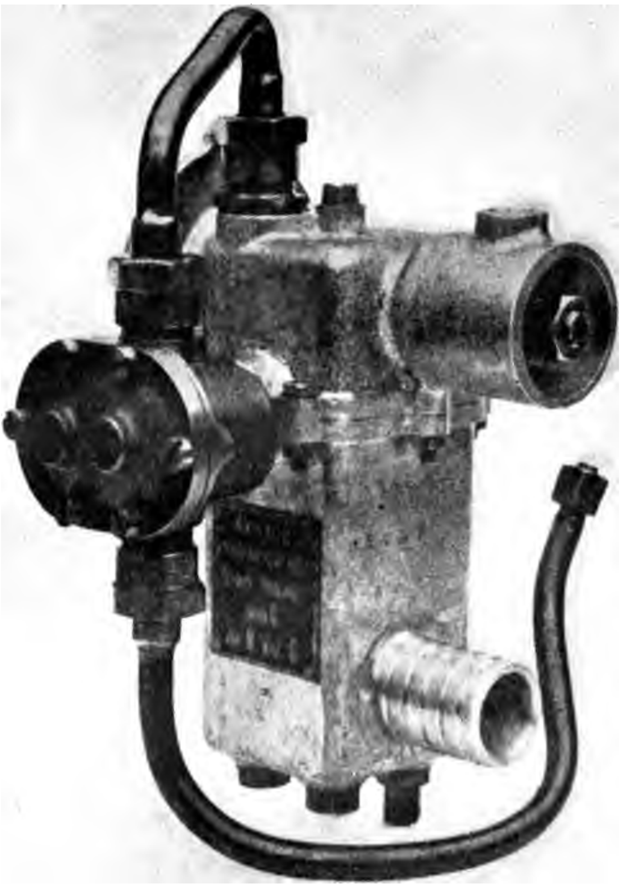


FIG. 78.—Oil-heating Device for the Gnome Engines, constructed by Messrs. Peter Hooker, Ltd., of Walthamstow, London.

sumption ½ gallon per hour. Lubrication is forced by means of a pump drawing oil from a tank in the crankchamber; an auxiliary oil tank is also fitted. The firing order of the cylinders is 1, 2, 4, 6, 5, 3. Two views of this engine are shown in Figs. 81 and 82.

PLATE 26A.

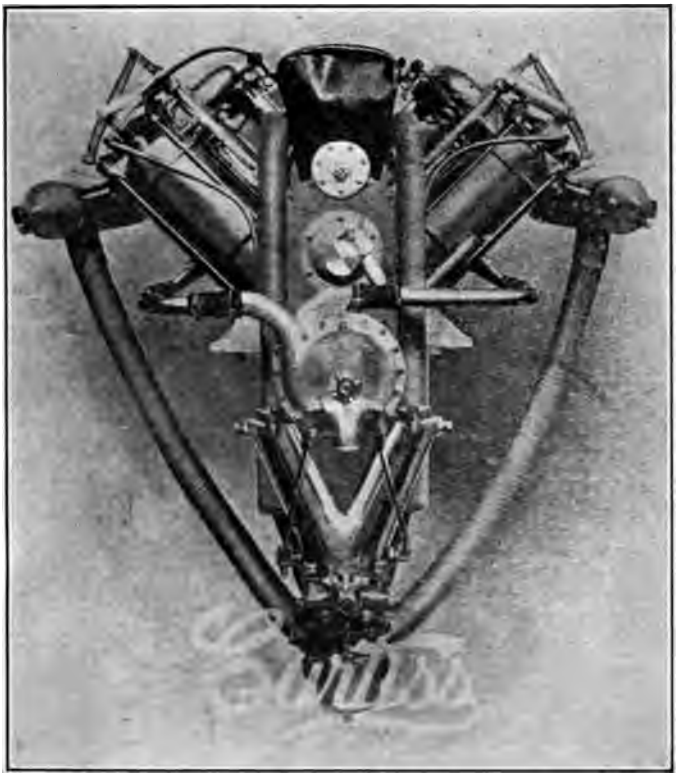


FIG. 79.—The 100 horse-power Curtiss aeroplane engine, type OX.

PLATE 26B.

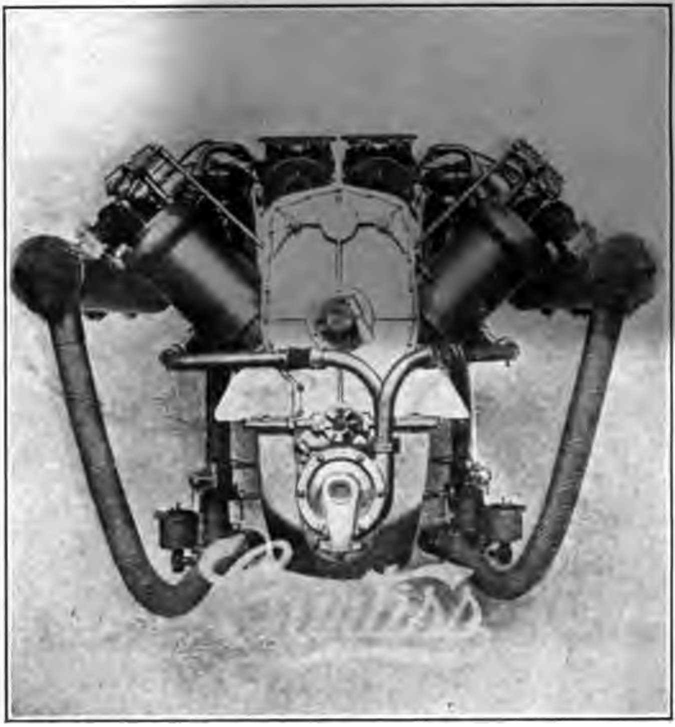


FIG. 80.—The 200 horse-power Curtiss aeroplane engine, type VX.

PLATE 26c.

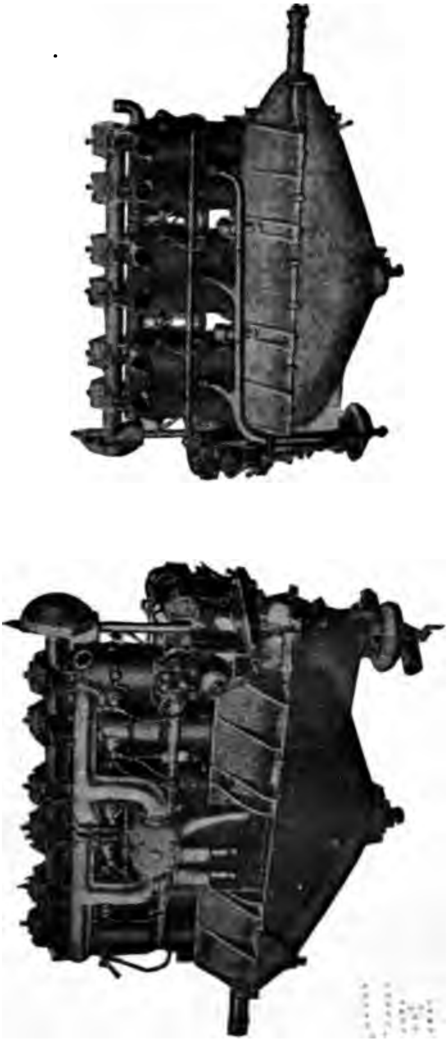


Fig. 81-2.—The 100 horse-power Six-cylinder Mercédès Aeroplane Engine

To face p. 94, Kean, Aeronautical Engines.]

APPENDIX

We have dealt principally with engines of 100 horse-power, but engines of 200 horse-power are in common use, and in the near future we may expect still more powerful engines—probably the day of the 1,000 horse-power aeroplane engine is close at hand.

One is frequently asked to express an opinion as to which type of engine will survive the present competitive era, and naturally a satisfactory answer cannot be readily put forward. After due consideration the Author ventures to predict that, putting on one side such impracticable machines (at present) as internal combustion turbines and wireless-controlled electric motors, the six- or twelve- or eighteen-cylindered vertical-in-line type will most likely come out on top. The radial and rotary types have too much wind surface exposed and have as a rule to be placed in front of the pilot; the Vee engine is not an attractive mechanical proposition, and the advantage gained by the reduction in engine length is partly discounted by the increased width and other disabilities mentioned previously in the text. The use of ball-bearings in connecting rod big ends which is now so commonly advocated is absolutely wrong, and in most cases their use for main engine bearings is a doubtful advantage. Ball and roller bearings have many advantages for certain purposes, but their principal use should be for bearings which are subjected to steady loads and have no pounding action upon them. Ball thrust bearings for propeller drive or gears are of course ideal. The practice of holding the cylinders on to the crank chamber by long bolts attached at the head end is good as it relieves the barrel of longitudinal tensile stress. The best position for the valves should be side by side in the centre of the cylinder head, but this often leads to pre-ignition and knocking due to overheating of the exhaust valve. Great care must be taken with the heat treatment of the exhaust valve especially if the engine is likely to run much on a weak mixture. The position of the sparking plugs is also a matter for careful thought. In many cases it will be found better to sacrifice much *theoretical efficiency* for a little practical experience and place the valves and plugs in a quiet little pocket of their own; also it would be better sometimes to overcool the engine a little in the neighbourhood of the valves, leaving the barrel to take care of itself to a greater extent than at present. The abolition of the oil pump with its attendant drive and pipes may also be one of the future developments in design. In the matter of pistons the cast-iron article still holds a prominent place in spite of the introduction of aluminium alloys; the steel cylinder suits the cast-iron piston and the steel piston will do quite well in the cast-iron cylinder, but the fixing of the gudgeon pin and the stiffening of the piston head by ribs are most readily carried out in a casting. The overhead camshaft is not in favour as it introduces new troubles to add to other misfortunes. In the matter of carburation there is still room for improvement, and a device which embodied some of the best features of two of the leading carburettors, while eliminating the less desirable, would probably come quite near to perfection. The ignition device, i.e. the high tension magneto as we know it, is a splendid machine and leaves little room for improvement, but the question of sparking plugs is not yet settled. The plug which will always spark when it should do has yet to be found.

INDEX

A

Acceleration of piston, 47
Accessories, weight of, 26
Aeroplane engines, classification of, 14
Air-cooled engines, 14
  bivalve, 15
  Vee engines, 16
Anzani engine, 17, 83
  dimensions of, 84
  firing order of, 41
  inertia forces, 52
  oil consumption, 84
  petrol consumption, 84

B

Balance of six cylinder vertical Engine, 49
Balancing sliding parts, 44
Beardmore-Austro-Daimler, 19
Beardmore Engine, 70
  bearings, 71
  dimension of, 73
  dual ignition, 71
  internal arrangement, 70
  oil consumption, 73
  petrol consumption, 73
  weight per B.H.P., 73
Bearings, Beardmore engine, 71
  best types of, 95
Benz engine, 19
Bi-valve air-cooled engines, 15
Bosch magneto, 74

C

Camshaft and crankshaft, weight of, 26
  overhead, 18
  position of, 96
  Wolseley engine, 73
Carbon deposit, cause of, 60
Carburation, 55
Carburettor, Anzani engine, 84
  Beardmore, 72
  junction of choke tube, 56
  Salmson engine, 81
  Wolseley engine, 74
Choke tube, 56
Claudel-Hobson carburettor, 55, 57, 74
Comparison of high and low duty engines, 22
  of vertical and Vee engines, 24
  of water-cooled and semi-air-cooled engines, 22
Compensating jet of Zenith carburettor, 58
Compression stroke, 32
Condenser, object of, 66
Connecting rod, obliquity of, 47
  Anzani engine, 82
  Salmson engine, 76
Continuity of torque, 23
Crankcase, Anzani engine, 83
  Beardmore, 71
  Gnome engines, 89
  weight of, 26
  Wolseley, 74
Crankchamber weight, diminished in Vee engines, 27
Crankshaft, Anzani engine, 84
  Gnome engine, 86
  speed of, 22
Crankpin bearing (Anzani), 84
  Salmson engine, 79
Curtiss engine, 90, 91, 92
Cylinder barrel of Wolseley engine, 75
Cylinder bore and mean effective pressure, 21
Cylinders, Anzani engine, 83
    arrangement of. 83
  arrangement of, 24
  Beardmore, 70
  choosing number of, 29

Cylinders—Continued
  Gnome engine, 89
  L-headed, 19
  Method of holding, 95
  Salmson engine, 77
    arrangement of, 77
  weight of, 26
  Wolseley, 74

D

Dead weights of various types of engines, 28
Diameter of cylinder bore, importance of, 21
Dual ignition of Beardmore engine, 71

E

Efficiency, methods of securing, 13
  power, 12
  thermal, 12
  weight, 13
Eight-cylinder Vee engine, firing order, 35
    inertia forces, 51
Electrical connection of magneto, 67
Engine parts, relative weights of, 26
Exhaust gases, temperature of, 59, 60
  stroke, 32
  temperature, 60
  valves, Anzani engine, 83
    Gnome engine, 86, 88
    water-cooled, 16
Explosive mixtures, effect of strength of, 59
Explosion stroke, 32

F

Firing impulses, distribution of, 29
  order Anzani engine, 41
    eight-cylinder Vee engine, 35
    four-cylinder Vertical engine, 34
    radial engine, 41

Firing impulses—Continued
    Salmson engine, 81
    six-cylinder vertical engine, 38
Fuel consumption, 59
Flywheel, weight of, 26
Four-cylinder vertical engine, firing order, 34
Four-stroke cycle, 29

G

Gear wheels, Salmson engine, 80
Gearing, weight of, 26
Gnome engine, 15
  formation of explosive mixture in, 88
  inertia forces in, 52
  mechanism of, 86
  monovalve type, 15, 86
  test arrangements, 87
Green engine, 17

H

High-duty engine, saving of weight in, 23
High-tension distributor, 64
  electrode, 65

I

Ignition, 62
  speed of propagation of flame in, 68
  two-point, 69
Inertia force of piston, 44, 48
  forces, 25, 49
    Anzani engine, 51
    eight-cylinder Vee engine, 25, 51
    nine-cylinder Gnome engine, 25
    radial engines, 25, 51
    rotary engines, 25
    Salmson engine, 52
    six-cylinder vertical engine, 25
    twelve-cylinder Vee engine, 50
    Vee engines, 25

Inlet valves, Anzani engine, 83
  Beardmore, 72
  early opening of, 32
  Gnome engine, 85
  Le Rhone engine, 85

J

Jacket water, heat lost to, 59

L

L-headed cylinders, 19
Le Rhone engines, 15, 86
Low-tension circuit, 65
  windings, 67
Lubrication, Anzani engine, 84
  Beardmore engine, 72
  Salmson engine, 81
  Wolseley engine, 74

M

Magneto, details of, 62
  electrical connection of, 67
Master rod, Gnome engine, 89
  Le Rhone engine, 85
Mean effective pressure and cylinder bore, 21
Mercedes engine, 19, 93, 94
Monovalve air-cooled engines, 15
  Gnome engine, 86
Motion of a piston, 45
Mushroom type valve, 81

N

Nine-cylinder Gnome engine, inertia forces, 53
Number of cylinders, choosing, 29

O

Obliquity of connecting rod, 47
Obturateur rings, Gnome engine, 89
Odd cylinders, necessity for, in rotary engines, 36
Oil and petrol, weight required for four hours' run, 27
  consumption, Anzani engine, 84
Oil and petrol—Continued
  Gnome engine, 89
  in different types of engine, 25
  Salmson engine, 82
Oil pump, Gnome engine, 80
  Salmson engine, 81
Overhead camshaft engine, 18

P

Petrol consumption, 59
  Anzani engine, 84
  effect of mixture on, 59
  Gnome engine, 90
  in different types of engine, 25
  Salmson engine, 82
Piston, acceleration of, 47
Piston, actual motion of, 46
  Anzani engine, 84
  Beardmore, 71
  ideal motion of, 45
  inertia force of, 48
Piston, material of, 96
  Salmson engine, 78
  Wolseley engine, 74
  weight of, 26
Power efficiency, 12
  of engine, dependent on weight of fuel burnt, 60
  output, comparison of different types of engine, 25
  plants, total weights of, 28
Primary inertia forces, 49
Propeller, speed of, 23

R

Radial engine, air-cooled, weight in running order, 28
  firing order of, 40
  inertia forces, 25, 52
  water-cooled, 18
    weight in running order, 28
Rénault engine, 16
Rotary engine, inertia forces in, 25, 52
  reason for odd number of cylinders, 36
  weight in running order, 28

engine, dimensions of, 21, 22
Seven-cylinder radial engine, inertia forces, 52
Six-cylinder Beardmore engine, 70
 vertical engine, firing order, 36
Sparking plugs, 64
 position of, 96
Speed of crankshaft, 22
 propeller, 23
Stream-line valve, 81
Suction stroke, 29
Sunbeam water-cooled Vee engine, 20

T

Temperature of exhaust, 60
Ten-cylinder radial engine, inertia forces, 52
Test arrangement, Gnome engine, 87
Thermal efficiency, 12
 effected by richness of mixture, 59
Timing of valves, 32
Throttle control valve, Gnome engine, 88
Torque, continuity of, 23
Two-point ignition, 69

in W
in Sa
stream
timing
Vee engin
pare
air-coole
crankcha
eight-cyli
35
inertia fo
semi-air-c
sunbeam,
water-cool
Wolseley,
Vertical and
pared,
Vertical en
weight
firing orde
35
six-cylind
long tappet
over-head c
six-cylinder,
firing ord
water-cooled,
weight in
Vertical-in-line
tages of,
tappet-rod en

V

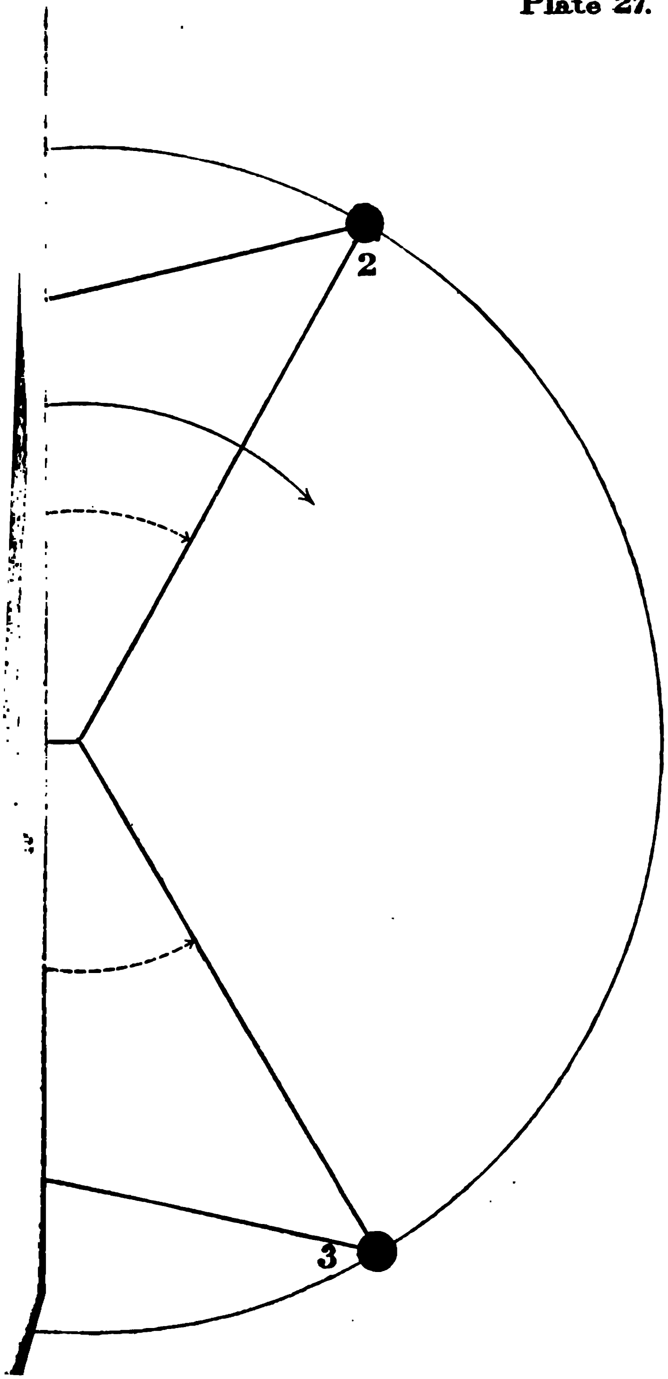
Water jackets, Beardmore, 71
    Salmson engine, 78
    Wolseley, 74
  pump, Salmson engine, 81
Weight efficiency, 13
  of high-duty engine, 23
  of oil and petrol for various types of engines, 28
  of parts of vertical engine, 26
  of vertical engines, 26
  per H.P. of various types of engines in running trim, 28
  relative of air-cooled and water-cooled engines, 22
Wolseley engine, 73
    details of, 21
    dimension of, 76
  High-duty engine, 23
  semi-air-cooled engine, 16
  water-cooled Vee engine, 20

Z

Zenith carburettor, 55, 58, 81

JUN 12 1919

Plate 27.



TECHNICAL BOOKS

PUBLISHED BY

SPON & CHAMBERLAIN

120-122 LIBERTY ST. NEW YORK

ELECTRICITY

THE STUDY OF ELECTRICITY AND ITS LAWS FOR BEGINNERS. By N. H. Schneider. 88 pages, 54 illustrations, 7¼ x 5 in., paper, 25 cents.

DRY BATTERIES, How to Make and Use Them. By N. H. Schneider. 59 pages, 30 illustrations, 7¼ x 5 in., paper, 25 cents.

ELECTRICAL CIRCUITS AND DIAGRAMS, PART ONE. By N. H. Schneider. Principally devoted to direct current. 7¼ x 5 in., paper, 25 cents.

ELECTRICAL CIRCUITS AND DIAGRAMS, PART TWO. By N. H. Schneider. Principally devoted to alternating and power plant work. 7¼ x 5 in., paper, 25 cents.

SMALL ELECTRICAL MEASURING INSTRUMENTS. How to make and use them. A Practical handbook by P. Marshall. 90 pages, 59 illustrations, paper, 25 cents.

STATIC ELECTRICITY, Simple Experiments in. A series of instructive and entertaining experiments. By P. C. Bull. V + 68 pages, 49 illustrations, 7¼ x 5 in., paper, 25 cents.

MODERN PRIMARY BATTERIES, Their construction, use and maintenance. By N. H. Schneider. XII + 94 pages, 55 illustrations, 7¼ x 5 in., paper, 25 cents.

WIRELESS TELEPHONE CONSTRUCTION. A comprehensive explanation of a wireless telephone equipment for receiving and sending, with details of construction. By N. Harrison. 74 pages, 43 illustrations, paper, 25 cents.

PLANS AND SPECIFICATIONS FOR WIRELESS TELEGRAPH SETS BY A. F. COLLINS.

Part 1. Complete instructions on making an experimental set, also a 1 to 5 mile set. 55 pages, 37 illustrations, 12mo., paper, 25 cents.

Part 2. Complete details for a 5 to 10 mile set, also a 10 to 25 mile set. 80 pages, 63 illustrations, 12mo., paper, 25 cents.

MAKING WIRELESS OUTFITS. A concise and simple explanation of the construction and use of inexpensive wireless equipment. By N. Harrison. 61 pages, 27 illustrations, cloth, 50 cents.

PRACTICAL ELECTRICS. The universal handy book on everyday electrical subjects. 135 pages, 126 illustrations, 7½ x 5 in., cloth, 50 cents.

HOW TO INSTALL ELECTRIC BELLS, ANNUNCIATORS AND ALARMS, including battery, wiring, etc. By N. H. Schneider. Second edition, considerably enlarged. XII + 88 pages, 70 illustrations, 7¼ x 5 in., cloth, 50 cents.

ELECTRICITY

INDUCTION COILS. How to make and use them. A practical handbook on the construction and use of medical and spark coils, by P. Marshall. Revised and enlarged. 70 pages, 35 illustrations, cloth, 50 cents.

INDUCTION COILS, How to Make and Use Them, including Ruhmkorff, Tesla and Medical coils. By H. S. Norrie. Second edition, revised and enlarged. XVI + 269 pages, 79 illustrations, 7½ x 5¼ in., cloth, $1.00.

INDUCTION COILS. Experimenting with. Practical directions for making the apparatus and operating it, by N. H. Schneider. 73 pages, 25 illustrations, 25 cents.

TELEGRAPHY FOR BEGINNERS. The standard method with lessons. By W. H. Jones. Second edition, revised; VI + 58 pages, 19 illustrations, cloth, 50 cents.

SMALL ACCUMULATORS. How to make and use them, by P. Marshall. Third edition, 80 pages, 40 illustrations, 12mo., cloth, 50 cents.

ELECTRIC GAS IGNITING, How to Install Gas Lighting Apparatus. By H. S. Norrie. VIII + 101 pages, 57 illustrations, 7½ x 5 in., cloth, 50 cents.

MAGNETO TELEPHONE. Its construction, fitting up, and use. By N. Hughes. VII + 80 pages, 23 illustrations, cloth, 50 cents.

WIRING HOUSES FOR THE ELECTRIC LIGHT. By N. H. Schneider. Second edition, revised and enlarged. VIII + 112 pages, 45 illustrations and 9 page plates, 7¼ x 5 in., cloth, 50 cents.

LOW VOLTAGE ELECTRIC LIGHTING WITH THE STORAGE BATTERY. Showing latest American types and complete outfits. By N. H. Schneider. Second edition, revised and enlarged. X + 94 pages, 31 illustrations, 7¼ x 5 in., cloth, 50 cents.

ELECTRIC WIRING CALCULATION. The Herrick Planigraph, arranged as a set of four moving cards, solving all problems of wiring for branches, feeders and mains, electric railways and long distance transmission, giving the size of copper conductors required. Size, 5½ x 5¾ in., 50 cents.

THE MECHANICS OF ELECTRICITY, by F. J. B. Cordeiro. The object of this work is to show that Electricity and the Ether are identical. VI + 78 pages, 7 illustrations, 7¾ x 5½ in., cloth, $1.25.

THE WIMSHURST MACHINE. How to make and use it, by A. W. Marshall. With complete detailed drawings. Second edition. 112 pages, 30 illustrations and drawings, cloth, 50 cents.

MAGNETS AND MAGNETISM SIMPLY EXPLAINED, by A. W. Marshall. A practical treatise without mathematics, including the principles of both permant and electro magnets. 90 pages, 49 illustrations, cloth, 50 cents.

ELECTRICITY

ALTERNATING CURRENTS SIMPLY EXPLAINED. An elementary handbook on generators, transformers and motors, by A. W. Marshall. 90 pages, 33 illustrations, cloth, 50 cents.

PRACTICAL ALTERNATING CURRENTS AND POWER TRANSMISSION. By N. Harrison. Specially intended for the practical man. 375 pages, 172 illustrations, 7½ x 5¼ in., cloth, $1.50.

MAGNETISM CURVES OF MAGNETIC DATA, for various metals. By S. P. Thompson. A large chart 25 in. x 16 in. 25 cents.

DYNAMO DESIGN, SCHEDULES FOR. These sheets are for carrying out dynamo designs according to the method laid down by S. P. Thompson. Five sheets to a set; size 10½ in. x 8 in. Per set, 25 cents. Special price on a quantity.

ELECTRICAL INSTRUMENTS AND TESTING. By N. H. Schneider. Fourth edition, greatly enlarged. XXIV + 288 pages, 133 illustrations, 7¼ x 5 in., cloth, $1.00.

ELECTRIC POWER PLANTS, Their care and management. A practical handbook for engineers. By N. H. Schneider. 290 pages, 203 illustrations, 7½ x 5¼, cloth, $1.50. Full limp leather, gilt edges, $2.50.

ELECTRIC LIGHT FOR THE FARM. By N. H. Schneider. Being Low Voltage Electric Lighting, and Wiring Houses for the Electric Light, complete in one volume. 224 pages, 76 illustrations, 7¼ x 5 in., cloth, $1.00.

STEAM ENGINEERING

MODEL STEAM TURBINES. How to design and build them. By H. H. Harrison. A practical handbook for model makers. 85 pages, 75 illustrations, paper, 25 cents.

MODEL STEAM ENGINE DESIGN. A handbook of practical information, formulas and tables. By R. M. DeVignier. IX + 94 pages, 34 illustrations, 7¼ x 5, paper, 25 cents.

THE FIREMAN'S GUIDE. By J. P. Dahlstrom. A practical handbook on the care of steam boilers, IV + 28 pages, 7 x 5 in., cloth, 50 cents.

A B C OF THE STEAM ENGINE, with a description of the automatic governor, by J. P. Lisk. 30 pages, large folding plates, cloth, 50 cents.

¼ x 6 in., c

CENTRIFUGAL FANS. Theor
practical treatise on. Fans or mov
large quantities at comparatively lov
By J. H. Kinealy. XIV + 206 pag
grams, limp leather pocketbook, $5.0

STEAM ENGINES AND BOILERS
mentary textbook on, for the use of
By J. H. Kinealy. Sixth edition, V
pages, 107 illustrations, 8vo., cloth, $2

SLIDE VALVE SIMPLY EXPLAI
W. J. Tennant. Revised and enlarge
H. Kinealy. A practical handbook for e
VII + 83 pages, 41 illustrations, 7¼
cloth, 50 cents.

SLIDE VALVE. Instruction chart
full instructions for using it. By J.
Blueprint 14 x 10½ in., 25 cents.

LOW PRESSURE STEAM HEATI
series of charts on heavy folding card
H. Kinealy. Size 13 x 9¼ in., $1.00.

MECHANICAL DRAFT. A practic
book for engineers and designers fo
plants. By J. H. Kinealy. 156 pages,
plates, 6¾ x 4½ in., cloth, $2.00.

THEORETICAL AND PRACTICAL
NIA REFRIGERATION. A practica
book for engineers interested in the
ment of ice and refrigerating machin
I. I. Redwood. IX + 146 pages, 14
tions, 7¼ x 5 in., cloth, $1.00.

GAS ENGINES

GAS ENGINE, IN PRINCIPLE AND PRACTICE. Two-cycle and four-cycle types, with description of various design. With notes on gas producers. By A. H. Goldingham. 195 pages, 107 illustrations, 9¼ x 6¼ in., cloth, 75 cents.

CARE AND MANAGEMENT OF GAS ENGINES. A practical handbook on. By G. Lieckfield. XIV + 103 pages, 14 illustrations, cloth, 50 cents.

THE DESIGN AND CONSTRUCTION OF OIL ENGINES. With full directions for erecting, testing, installing, running and repairing; including kerosene engines, and an Appendix on Diesel Engines. By A. H. Goldingham. XXII + 308 pages, 142 illustrations, 48 full page plates, cloth, $2.50.

MARINE AND STATIONARY DIESEL ENGINES. Described and illustrated with numerous formulae for their design and instructions for installation and operation. By A. H. Goldingham. XX + 206 pages, 135 illustrations, 10 folding plates, 7¾ x 5 in., cloth, $3.00.

CROSS SECTION PAPERS

THE HANDY SKETCHING BOOK, ruled plain, 8ths to one inch, printed on both sides, size 5 x 8 in., limp card back, 25 cents.

ELECTRICIANS' SKETCHING BOOK, ruled 10 to 1 inch, with heavy inch lines, blue ink, printed on both sides, size 5 x 8 in., 25 cents.

THE HANDY SKETCHING PAD. Plain 8ths to 1 inch, blue ink, printed on one side, size 8 x 10 in., 25 cents.

THE ELECTRICIANS' PLOTTING PAD. Scale 10 to 1 in., with heavy inch lines, blue ink, printed on one side, size 8 x 10 in., 25 cents.

Scale 8 to 1 inch, heavy inch lines, size 17 x 22 inches, per quire, $1.00.

Scale, 10 to 1 inch, heavy inch lines, ledger paper, size 17 x 22 inches, per quire, $1.00.

Scale, 16 to 1 inch, heavy inch lines, size 9 x 11 inches, per hundred sheets, $1.00.

ANNUAL SUBSCRIPTION.—POST-PAID.

(Prices Subject to Change)

Models, Railways and Locomotive. (M)	2.00
The Process Engravers' Monthly (M)	2.00
The Power User (M)	2.00
Science Abstracts, sections A and B (M)	7.50
Science Abstracts, either section (M)	4.50
Woodworker and Art Metalworker (M)	1.50
JUNIOR MECHANICS	1.00
The Model Engineer (W)	4.00

Cordeiro, the most complete
on this subject. VII + 105 pages, 8½
in., cloth, $1.50.

**BAROMETRICAL DETERMINATIC
HEIGHTS.** A practical method of bar
cal levelling and hypsometry. By F.
Cordeiro. Second edition, revised and en
6 x 4 in., limp cloth, 50 cents.

TIME OF THE WORLD. Universal
Card Model. Printed in two colors o
card, with movable disk, 9 x 7 in., 25 ce

CONCRETE DAM CONSTRUCTION.
Caisson as a new element in Concrete
Construction. By O. G. Aichel. 32 pa
diagrams, 6 large folding plates, 9¾ x 7
paper, $1.00.

REINFORCED CONCRETE BUILI
The Elements of, by G. A. P. Middleton
pages, 58 illustrations, 7½ x 5 in., cloth,

CERAMIC GLAZES. Arranged for he
the soft porcelain kiln. By H. Rum Be
Series A, Leadless Sanitary Glazes for
waterproof glazed brick and stone; porc
enamelled fire-clay sanitary ware; soft p
lain; strong clay ware. From the seven cl
formulas for any admixture of glazed
terials can be obtained. Folio, cloth, $10.

GAS ANALYSTS MANUAL, by Ja
Abady, incorporating Hartley's Gas Anal
Manual and Gas Measurement, with r
valuable tables of data. XV + 560 page
illustrations, 9 folding plates, 8½ x 5½
half leather, $6.50.

SODA FOUNTAIN FORMULAS. A pr
cal receipt book of

MISCELLANEOUS BOOKS

MOLESWORTH METRICAL TABLES, containing linear, square, cubic and capacity measures; weights; combinations; prices; electrical, etc.; heat. 95 pages, 5 x 3 in., cloth, 75 cents.

FRENCH MEASURES AND ENGLISH EQUIVALENTS. Giving equivalents in inches, and decimals of an inch, of from 1 to 1000 millimetres, and 1 to 100 metres, and table of fractional parts of an inch with corresponding decimals. By J. Brook. 80 pages, 4 x 3 in., limp cloth, 40 cents.

BUCHANAN'S TABLES OF SQUARES. Containing the square of every foot, inch, and sixteenth of an inch between 1/16 of an inch and 50 feet. By E. E. Buchanan. 11th edition, 7 x 4 in., limp cloth, $1.00.

PATENTS, INVENTIONS, How to protect, sell and buy them. By F. B. Wright. 108 pages, 1 plate, 7¼ x 5 in., paper, 25 cents.

WINDMILLS & WIND MOTORS. How to build and run them. By F. E. Powell. Practical guide to the construction of small windmills with detail drawings. VI + 78 pages, 76 illustrations, 7¼ x 5 in., cloth, 50 cents.

SIMPLE SOLDERING. Both hard and soft, with directions for making home-made apparatus. By E. Thatcher. VIII + 76 pages, 52 illustrations, 7¼ x 5 in., 50 cents.

WOODWORK JOINTS.. How to make and where to use them. New edition, revised and enlarged, 101 pages, 178 illustrations, 7¼ x 5 in., paper, 25 cents.

THE MODEL VAUDEVILLE THEATRE. How to construct and operate it. By N. H. Schneider. 90 pages, 34 illustrations, 7¼ x 5 in., paper, 25 cents.

USEFUL ANIMALS, and their Products. A dictionary of, with glossary of trade and technical terms, by P. L. Simmonds, 6¾ x 4¼ in., cloth, 80 cents.

HOW TO BUILD A TWENTY-FOOT BI-PLANE GLIDER, by A. P. Morgan. A practical handbook on the construction of one of these machines, with full detailed drawings. 60 pages, 31 illustrations, cloth, 50 cents.

HISTORIC MINES OF MEXICO. Handbook to the. By C. B. Dahlgren. Arranged in tabulated form with two maps, 24 x 9 in., limp card cover, $1.00.

heads: New appliances, arrange
card tricks, miscellaneous tricks, black ar
illustrations, 8 x 5¼ in., handsomely bour
$1.65 post paid.

A NEW BOOK ON

Magneto Igniti

ITS

Principles and Applicatio

WITH

Special Reference to

AVIATION ENGINES

BY

MICH. E. TOEPEL

Instructor U. S. Government School for
Study of M